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Radiation Laboratory

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ADD

HANDBOOK FOR UNITED NATIONS OBSERVERS

PIÑON TEST, ENIWETOK

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NO. 7601
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RETENTION CATEGORIES

A. Permanent:
- ____ Deviating from established policy
- ____ Setting precedent for future actions
- ____ Reflecting unusual sensitivity
- ✓ Historical interest
- ____ Subject of litigation

B. Six Years: ____ All others

9-8-77 (Date of review) (Name)

Printed for the U. S. Atomic Energy Commission

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DEDICATION

This handbook is dedicated to Dr. Mark M. Mills who conceived the Pinon Project and developed in detail the initial plan. Dr. Mills lost his life in a helicopter accident at the Eniwetok Proving Grounds on April 6, 1958 while making preparations for the execution of the experiment.

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PREFACE

This report comprises a handbook which was intended to be used by technical representatives from the United Nations Scientific Committee on the Effects of Atomic Radiation during a demonstration of a low fission to fusion yield explosion at the Eniwetok Proving Grounds. The handbook includes the operational concept and detailed technical descriptions of the methods of measurement which were to be used to determine the total energy release and the fission energy release. The total energy release was to be measured by rate of fireball growth measurements, and is described in the section entitled Fireball Determination of Total Yield prepared by Dr. Lewis Fussell of Edgerton, Germeshausen and Grier, Inc. The fission yield was to be determined by a radiochemical method and is described in Chapter III prepared by Dr. Roger Batzel of the University of California Radiation Laboratory.

This demonstration shot, designated Pinon, was cancelled on July 26, 1958. However, because the techniques described here had not been published previously it was considered desirable to publish the handbook.

GERALD W. JOHNSON
Technical Director

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ACKNOWLEDGEMENT

The development of the detailed plan, the preparation of the handbook, and the establishment of the laboratory facility in Berkeley was accomplished by the loyal efforts of many individuals. Among these were:

Dr. Harold Agnew, Los Alamos Scientific Laboratory

Commander Philip Bankhardt, Division of Military Application

Dr. Roger Batzel, UCRL

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Dr. Christopher Calsoyas, Editor, UCRL

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We would like to thank Dr. Eugene Huffman and the Analytical Chemistry Group at UCRL Berkeley for the provision of the laboratory space.

In addition, we are indebted to Major General Alvin Luedecke and members of Joint Task Force Seven who assisted in many parts of the program.

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FOREWORD

In 1954 the United States had already begun research to find means of drastically reducing the proportion of fission yield required in the thermonuclear explosion. This was an effort to develop nuclear explosives whose residual radioactivity could be confined more nearly to the area of blast and thermal damage, and to reduce greatly the amount of radioactive fallout which would be created from such explosions and given world-wide distribution. In July, 1956, the United States announced that it had achieved initial success in this program and in test firings had found that, with further development, weapons of drastically reduced fission yield could be produced.

The United States has with high priority continued the development of weapons of greatly reduced fission yield in proportion to total yield. A large portion of the current test series (Hardtack) is being devoted to making possible a material increase in the number of reduced-fission type weapons that can be produced.

On April 25, 1958, the United Nations, on behalf of the United States, offered to nations represented on the U. N. Scientific Committee on the effects of atomic radiation an invitation for their representatives to observe a demonstration of the firing of a weapon of greatly reduced fission yield. This demonstration will provide opportunity for the U. N. Observers to witness the firing of such a device and to make a determination, through instrumentation and laboratory analyses, of the weapon's total and fission yield.

It is the purpose of this handbook to describe briefly the operational procedure to be followed for the U. N. observance, the instrumentation to be used, and the analyses to be made.

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CHAPTER I

OPERATIONAL PROCEDURES

1. The measurement of the ratio of the fission yield to total yield will require several distinct operations. This handbook provides the basis for a division of labor which the Observers may find suitable. The demonstration and discussion of the measurement techniques at Berkeley will also provide a further basis for selecting different tasks for small groups of Observers.

2. The first contact between the Observers and the Piñon Test Officials will take place in Berkeley. Several days will be devoted to briefing the Observers on the measurement techniques. A thorough demonstration of the high-speed camera used to photograph the fireball will be given. The method of operating the comparator which measures the fireball image on the photographic film will be explained. An actual chemical analysis of radioactive materials will be done in order to make clear the method of determining the fission yield of the bomb.

3. At the end of the briefing sessions in Berkeley, the Observers will be transported by aircraft to Honolulu. At a time dependent on the completion of the regular test series at Eniwetok Atoll, the Observers will be transported by military aircraft to the Test Site at Eniwetok. The program at Eniwetok will deal only with those facilities that are required for staging the explosion, for measuring the fireball, and for obtaining radio-chemical samples. The device will be detonated on a barge moored in the lagoon on the northern side of Eniwetok Atoll. The fireball photographs will be made with cameras mounted on a 300-foot tower on Parry Island. The radio-chemical samples will be collected on filters carried by aircraft through the cloud resulting from the explosion.

4. The Observers may freely inspect the barge containing the bomb and the site on which the barge will be located. The container with the bomb will be weighed. The Observers will note that the tracer consists of U_3O_8 [redacted] The Observers may have free access to the barge until the time for detonation. Security measures prevent the inspection of any part of the device inside its container. For the same reasons, the Observers will not be given a sample of the radiochemical tracer.

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5. United States and Japanese maps will be used to determine the distance from the cameras to the barge.

6. The Observers will be shown the cameras to be used in photographing the fireball. The focal length of the lenses in the cameras will be measured. The timing device which correlates the fireball images with the time after detonation will be calibrated by using 200-cycle tuning forks. The Observers will view the selection of the filter paper to be installed in the sampling equipment which will be flown through the residue cloud of the explosion. They may also inspect the sampling equipment to be used.

7. The time at which the sampling aircraft takes off will be fixed roughly by the requirement that the people engaged in the sampling flight shall receive no more than one roentgen of radiation. The Observers will attend the flight briefing in which the flight plan is formulated. Upon return of the aircraft, the filter paper containing the radioactive residue will be removed by remote control and stored in a sealed container.

8. The films of the fireball will also be placed in sealed containers.

9. The filter paper container and the film containers will accompany the Observers to Berkeley for analysis.

10. In Berkeley the Observers may participate in the radiochemical analysis described below for determining the fission yield of the bomb. The Observers may also participate in the development of the fireball films. Duplicate film strips will be made available to the Observers for their retention. The dimensions of the fireball images will be measured on a comparator. The Observers may subsequently verify those dimensions on their own instruments.

11. The fission ratio of the bomb

$$\frac{\text{Fission yield in megatons}}{\text{Total yield in megatons}}$$

will then be established.

12. The Observers should be prepared for a possible delay of several days in the detonation of the device.

CHAPTER II

FIREBALL DETERMINATION OF TOTAL YIELD

1. Introduction

This section describes the theory of hydrodynamic growth and the derivation of the scaling laws, by means of which the total energy release of a nuclear explosion may be derived from the experimental observations. The observations are recorded by means of high-speed ciné cameras, during the phase of the explosion in which the shock front is luminous and coincident with the edge of the expanding fireball. The details of the experimental plan will be described, the parameters of the experimental equipment, the measurements that are required and the methods by which they are carried out and checked, the operational program, and finally the analysis equipment and procedures. The methods and numbers to be used have been developed over a period of thirteen years or more, not only from the published literature but also by detailed observations of all tests detonated by the United States Atomic Energy Commission.

The methods employed will provide a figure for the total yield of the Piñon shot that is accurate to approximately ± 5 percent; the data on which this figure will be based will be supplied to the United Nations Observers. In addition to this, facilities, equipment, techniques, and assistance will be provided so that the U. N. Observers may check the USAEC data in the field. Since some of the USAEC information--for example the survey data--has been accumulated over a period of seven years, it is impractical to carry out a field check to the same precision in just a few days. Thus the U. N. checking procedures will carry a greater margin of error than do the USAEC numbers; nevertheless the check should result in a figure for the energy release that is good to about ± 15 percent.

2. Hydrodynamic Theory and Scaling Laws

Photographic observations of the hydrodynamic growth of fireballs, produced at test explosions of the USAEC, have been studied both empirically and theoretically. The aim has been not only to derive a reliable method for evaluating the total energy release of each explosion, but also to understand some of the factors that perturb the growth pattern from that predicted by simple theoretical considerations. Empirical scaling constants

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have been derived through correlation of fireball-growth parameters with the total energy-release of fission bombs as determined by radiochemical means. On the other hand, theoretical studies have given the scaling constants in terms of the gamma (ratio C_p/C_v of the specific heats) for air at elevated pressures and temperatures; comparison of the two methods has actually thrown much light upon these characteristics of the medium in regions of strong shock.

It was shown, prior to the first atomic explosion at New Mexico, that the energy release may be expressed by

$$E = K\rho_o R^5 t^{-2} \tag{1}$$

where R is the radius of the spherical shock wave in an ideal medium, t is the time after the explosion, ρ_o is the atmospheric density, and K is a dimensionless parameter dependent upon the gamma of the medium inside the fireball. This relation was published by its originator, Sir Geoffrey I. Taylor[1], in a pair of articles that also compared the theoretical prediction with the experimental observations obtained during the New Mexico (Trinity) shot of 1945.

The observations obtained for the first several test shots of the USAEC showed that equation (1) was generally not satisfied until the latter phases of visible shock propagation; but that after a preliminary period of deviant growth it did indeed settle down and obey equation (1) for a time interval long enough to permit the empirical evaluation of the parameter K, in terms of the radiochemical yield. From this observation it follows that the gamma of air remains approximately constant for a considerable range of fireball temperatures and pressures.

When the quantities in equation (1) are expressed in CGS units, the first determination based on about six shots was K = 1.740. After a few years it appeared that the value K = 1.709 gave a better fit with the radiochemical data. This value continues to be good to this day, when applied to the prescribed portion of the hydrodynamic-growth curve.

3. Taylor Theory

Taylor considers the total energy release to consist of two parts:

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[1] G. I. Taylor, Proc. Roy. Soc. 201A, 159, 175 (1950).

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the kinetic energy, $\quad K.E. = 4\pi \int_0^R \frac{1}{2} \rho u^2 r^2 \, dr$

and the heat energy, $\quad H.E. = 4\pi \int_0^R \frac{pr^2}{\gamma - 1} \, dr$.

He starts with the equations of motion and continuity and the equation of state of a perfect gas. He determines the boundary conditions in terms of the Rankine-Hugoniot relations, which describe the conditions at the shock front. He finds it necessary to use approximations for these relations. The approximations are excellent as long as the pressures are very large compared with the ambient pressure. He concludes, on page 163, that the total energy release is given in equation (1) and that K is the sum of two integrals, each depending only on gamma.

Two errors may be noted in his derivation. On page 162, his equation 16a, the coefficient $(2\gamma/\gamma + 1)$ is inverted but is corrected in equation 16b. On page 161 a more fundamental error occurs, when he expresses the velocity of sound in air in terms of the variable parameter gamma; he should have used the value $\gamma_o = 1.40$. It turns out that this causes but a small error in the final result. It should also be noted that in calculating the energy release of the New Mexico shot, Taylor assumed an ambient air density of 1.25×10^{-3} g/cc, considerably greater than the true value 1.006×10^{-3}.

Taylor evaluates his integrals by means of step-by-step numerical integration, assuming several different values of gamma. These are summarized in his Table 3, page 180. He also derives some approximate formulae to facilitate these numerical calculations. We have re-stated his integral expressions, using $\gamma_o = 1.40$, and have evaluated them using the approximate methods.

The calculated values of K are found to be:

γ	K (Taylor)	K (re-calculation)
1.20	1.727	1.740
1.30	1.167	1.175
1.40	0.856	0.856

Several sources of data are available, from which the probable magnitude of gamma may be estimated. An estimate is all that can be made,

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since the actual temperatures in the fireball interior can only be surmised; the surface is certainly much cooler, and we can observe only the surface. The published data may be found in the literature.[2,3,4,5] These data are summarized in the curves given in Figure 1. Although there is some scatter to the data, it is clear that gamma goes through a broad minimum, and is of the order 1.2. Thus Taylor's theoretical scaling constant K = 1.740 differs from the experimental value K = 1.709 by only 2 percent, and we use the experimental number in evaluating all USAEC test shots. The energetic equation is, then,

$$E = 1.709 \rho_o R^5 t^{-2} \text{ (ergs)} \quad . \tag{2}$$

In practice the USAEC has measured the fireball diameter, rather than the radius, and has used a different set of units throughout. Expressing D in meters, t in milliseconds, ρ_o in grams/liter, and E in kilotons, relation (2) may be rewritten:

$$E = 1.272 \times 10^{-8} \rho_o D^5 t^{-2} \text{ kilotons} \tag{3}$$

where we use the conversion factor, one kiloton = 4.2×10^{19} ergs.

This conversion factor, although somewhat arbitrary, has been used consistently.[6]

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[2] J. G. Logan and C. E. Treanor, Tables of Thermodynamic Properties of Air from 3,000° to 10,000°K, Cornell Aeronautical Lab Report BE-1007-A3, January 1957.

[3] J. O. Hirschfelder and C. F. Curtiss, Thermodynamic Properties of Air, II, Naval Research Lab Report CM-472, University of Wisconsin, June 1948.

[4] J. Hilsenrath and C. W. Beckett, Tables of Thermodynamic Properties of Argon-Free Air to 15,000°K, Arnold Engineering Development Center Report AEDC-TN-56-12 (ASTIA AD-98974).

[5] Thermodynamic Properties of Highly Ionized Air, AFSWC-TR-56-35 (ASTIA AD-96303), Kirtland Air Force Base, New Mexico.

[6] S. Glasstone, Sourcebook on Atomic Energy, D. Van Nostrand, 1950.

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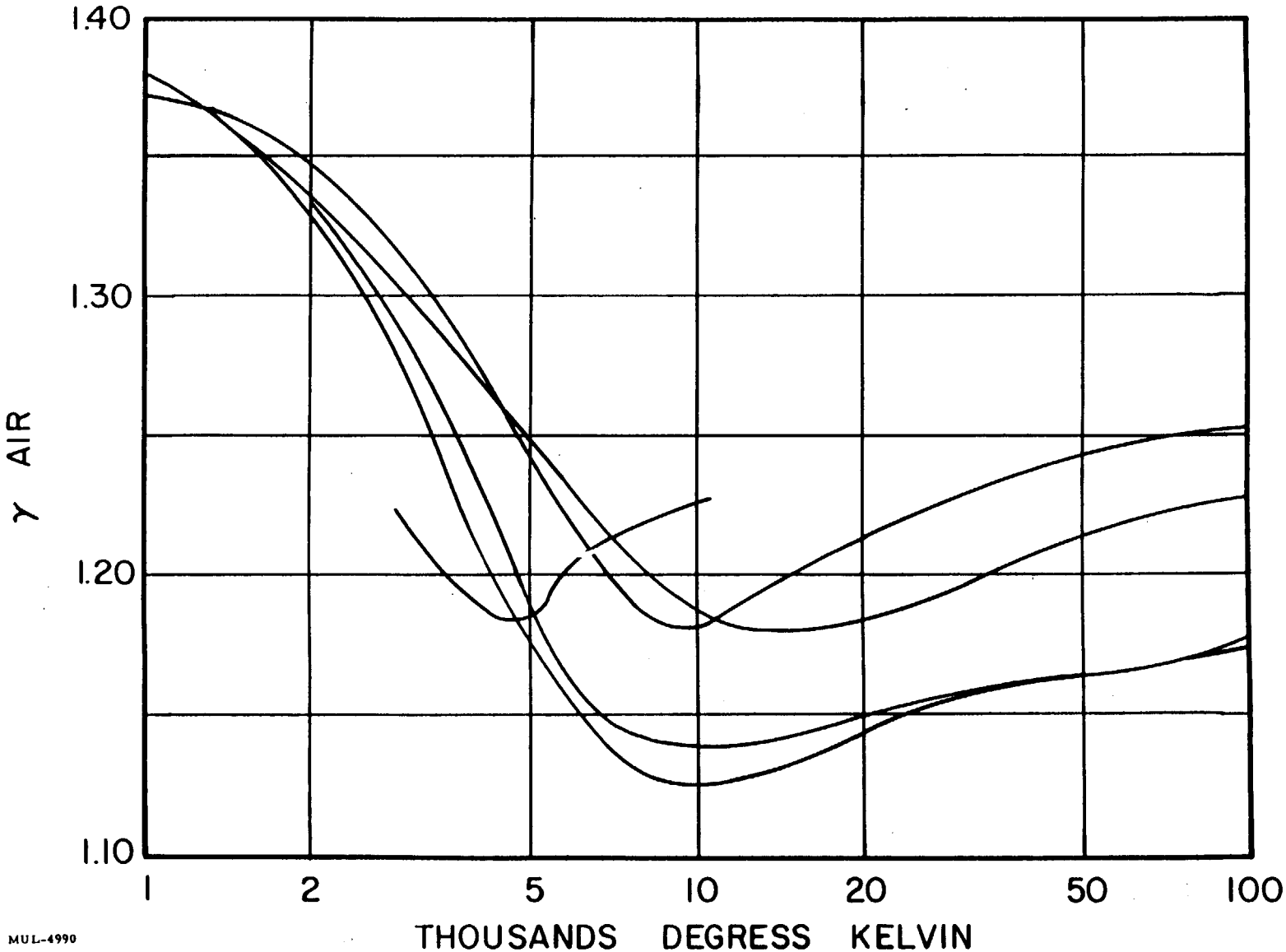

Fig. 1. Specific heat ratio gamma vs temperature for air.

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4. Expected Diameter/Time Curves for Piñon

It has been shown that the energy release from a nuclear explosion in an ideal medium is proportional to D^5/t^2, where D is the diameter of the symmetric shock front, and t is the time since detonation, at which this diameter obtains. In his theoretical derivation Taylor uses a quantity A, which is proportional to $D^{5/2}/t$; similarly we have found it useful to determine a parameter $\phi = D/t^{2/5}$ which is, like Taylor's A, approximately constant for a given shot. The deviations of ϕ from a constant are indicative of extraneous effects (such as varying gamma and also of large masses in the vicinity of the immediate explosion); the constancy of ϕ and the length of the interval over which it is constant lends confidence in the result. Further, a statistical analysis of the scatter of the experimental points in the constant-ϕ region can be used to establish confidence limits for the yield of the explosion.

Figure 2, a log-log plot of the expected diameter-vs-time data for yields of 1, 3, and 10 megatons, shows continuously increasing diameters, and slight deviations from straight lines. These deviations are magnified in the ϕ vs t plot of Figure 3; it is clear that ϕ becomes constant for the interval immediately preceding shock-breakaway, and this interval is used for scaling purposes. After breakaway the shock front is invisible (although it continues to grow with constant ϕ for a while longer), and the fireball itself lags behind. The fireball edges become indistinct and diffuse, and measurements are valueless as far as yield determinations are concerned. An ambient air density ρ_o = 1.15 grams/liter has been assumed in drawing these curves.

The trend of the data, in the early stages prior to constant-ϕ growth, is typical of shots which are exploded with only small amounts of material in the immediate vicinity of the detonation. When large masses must be consumed in the early phases, the growth pattern may be altered drastically; nevertheless it will settle down to the same constant ϕ.

5. Growth into Inhomogeneous Atmosphere

The high-yield nuclear explosion results in a fireball of large physical size. During the period in which yield measurements are to be made the top of the fireball may reach an elevation of about 3,600 ft, where the density of the air is about 90 percent of that at sea level. Thus the fireball

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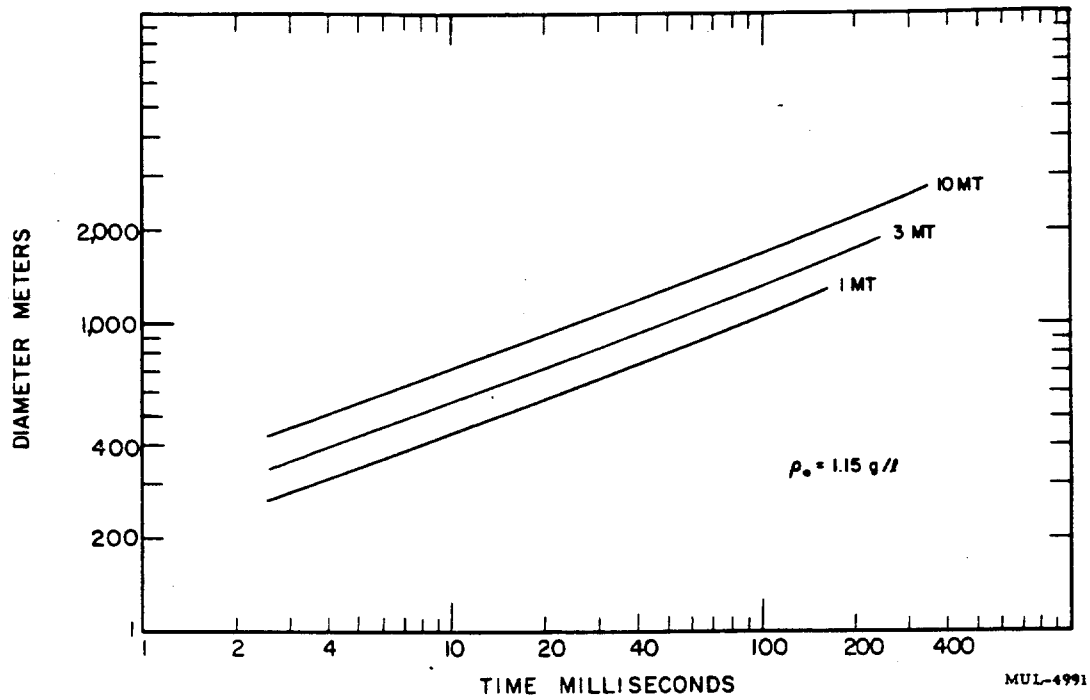

Fig. 2. Fireball growth, diameter vs time – surface shots, ρ_o = 1.15 g/liter.

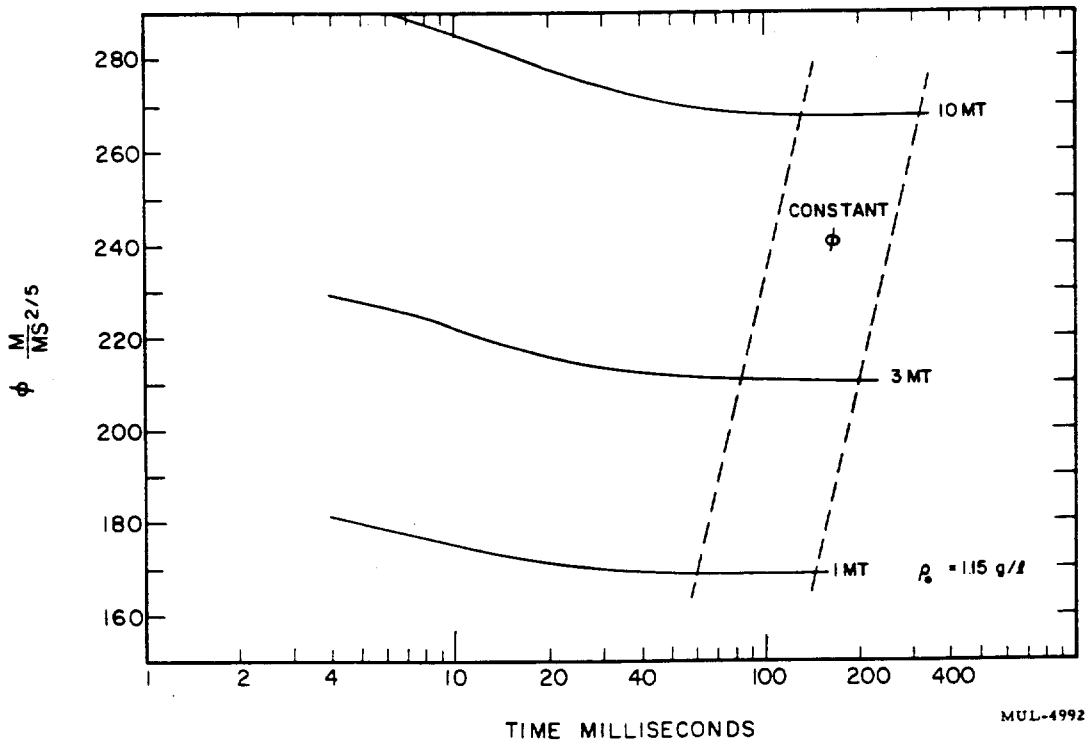

Fig. 3. Fireball growth, ϕ vs time – surface shots, ρ_o = 1.15 g/liter.

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can grow more rapidly, and to a greater extent, in the vertical direction than in the horizontal. The result will be a fireball shaped something like half an egg, rather than a perfect hemisphere.

The appropriate air density is that occurring at the center of the fireball area, such that half the area is above, and half below, the chosen altitude. For a hemisphere the altitude for center-of-area occurs at one-half the radius; we apply the same criterion to the distorted fireball, and use a different value of air density for each frame that we measure.

This effect does not alter the validity of the scaling laws; it simply introduces another step that must be taken in the analysis of the data and requires detailed data on the variation of air density with elevation.

6. Ground Reflection Effect

The effect of the rigid water surface must be considered for the Piñon shot, which is to be detonated within a few feet of sea level. The acoustic impedance of water is about 150,000 grams/cm^2/sec, whereas that of air is only 44. The result is that very little energy goes into the water; instead it is reflected almost perfectly back into the fireball and reinforces the shock front that was directed upward initially. The fireball becomes a nearly perfect hemisphere (excluding the effects of the inhomogeneous atmosphere which were just discussed), and the hemisphere represents half of a fireball having twice the apparent energy. Thus the factor F = 0.50 is introduced into the scaling equation, and the total yield for a surface burst is given by

$$E = 0.5\, K \rho_o D^5 t^{-2} \quad . \tag{4}$$

7. Measurements Required

It has been shown that four quantities must be measured in order to determine the total fireball energy release:

a) diameter of the fireball,

b) time after burst at which the measured diameter obtains,

c) air density (specific gravity) as function of altitude, and

d) ground-reflection factor.

The diameter of the image of the fireball, formed by the camera lens upon the film, will be measured in the analysis procedure. In order to relate this image to the size of the fireball itself, it is necessary to determine the

magnification factor of the optical system. This factor is equal to the ratio

$$\frac{\text{Distance, camera to plane perpendicular to optic axis containing the fireball diameter}}{\text{Lens focal length}}$$

Since the camera is operated at a slightly tilted angle, τ, the desired optic-axis distance equals the horizontal (ground) distance multiplied by cos τ. It is thus necessary to measure the horizontal distance, L, the focal length, f, and the angle of tilt, τ; once measured these quantities will remain constant for all frames exposed in a given camera. The USAEC measurements are each good to about 0.2 percent, and facilities will be provided to check them to something like 1.0 percent.

The time scale, relating each exposed frame to the time after detonation, will be determined from timing marks placed upon the film while the camera is being exposed. These marks will establish the time after detonation to better than 0.2 percent, and the observer-check will also be good to 0.2 percent.

The air density requires measurements of barometric pressure, temperature, and relative humidity, all three as functions of altitude. These quantities will be measured by means of weather balloons, released on Eniwetok Island shortly before detonation, which will telemeter the meteorological data to the ground. An independent measurement of the ground-level data will be made at the Control Point adjacent to the photo tower on Parry Island; this will utilize a Cenco mercury barometer and a standard sling-psychrometer. These instruments will be available for check-reading by the Observers, prior to and at shot time. From these readings the air density at ground level may be determined to a precision of about 0.2 percent; check values at various altitudes may be derived from this number through the use of the standard atmospheric data (such as those adopted by the NACA), to better than 0.5 percent.

The ground-reflection factor will be taken as equal to 0.50, and no measurements are contemplated.

8. Precision of Measurements

In addition to the individual measurement errors described above, one expects a reading error during the analysis of the films. For each frame

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read this error will be of the order of 1.0 percent; if 30 frames are read from a given film the resulting reading error will be about 0.2 percent. The determination of fireball diameter is thus subject to four probable errors. Each of these is about 0.2 percent for the AEC data, resulting in 0.4 percent in the diameter, and 2.0 percent in the yield. For the U. N. data three of the measurements are uncertain to 1.0 percent, and the fourth 0.2 percent; the result is 1.8 percent in the diameter and 9.0 percent in yield.

The timing error is in each case 0.2 percent, resulting in 0.3 percent in yield, and the air-density uncertainty causes 0.2 percent in the yield. Uncertainty in the scaling constant may amount to as much as 3.0 percent, owing primarily to the variable effects of the mass of the device, shielding, and barge. Combining all of these possible errors we find the resultant uncertainty in total yield to be about 4 percent for the AEC measurements and 10 percent for the Observer check, both within the prescribed 5-percent and 15-percent error limits.

It must be recalled that the AEC figures will be given to the Observers. The purpose of the Observer check is to verify the USAEC figures to a reasonable precision and not to furnish the accepted yield for the shot.

9. Cameras and Lenses

The growth of the nuclear fireball is recorded, for later analysis, by means of high-speed ciné cameras. Although many suitable cameras are available commercially, we find the Eastman High-Speed Type III to be most suitable for our purposes.

These cameras employ continuous, instead of intermittent, motion of the film. A glass prism, placed between lens and film, rotates at such a speed that the image is translated in the direction of the film motion; synchronism between the motions of the image and of the film is imperfect, but is more than adequate for most purposes. The housing around the prism serves as the shutter, blocking off the light when the image deflection-angle becomes large, and permitting light to pass for the next frame as it rotates further.

The Eastman camera, Figure 4, utilizes a 100-ft spool of 16-mm film. The prism is "two-sided", so that a complete prism revolution is required for every two frames. As a result, the duration of the exposure

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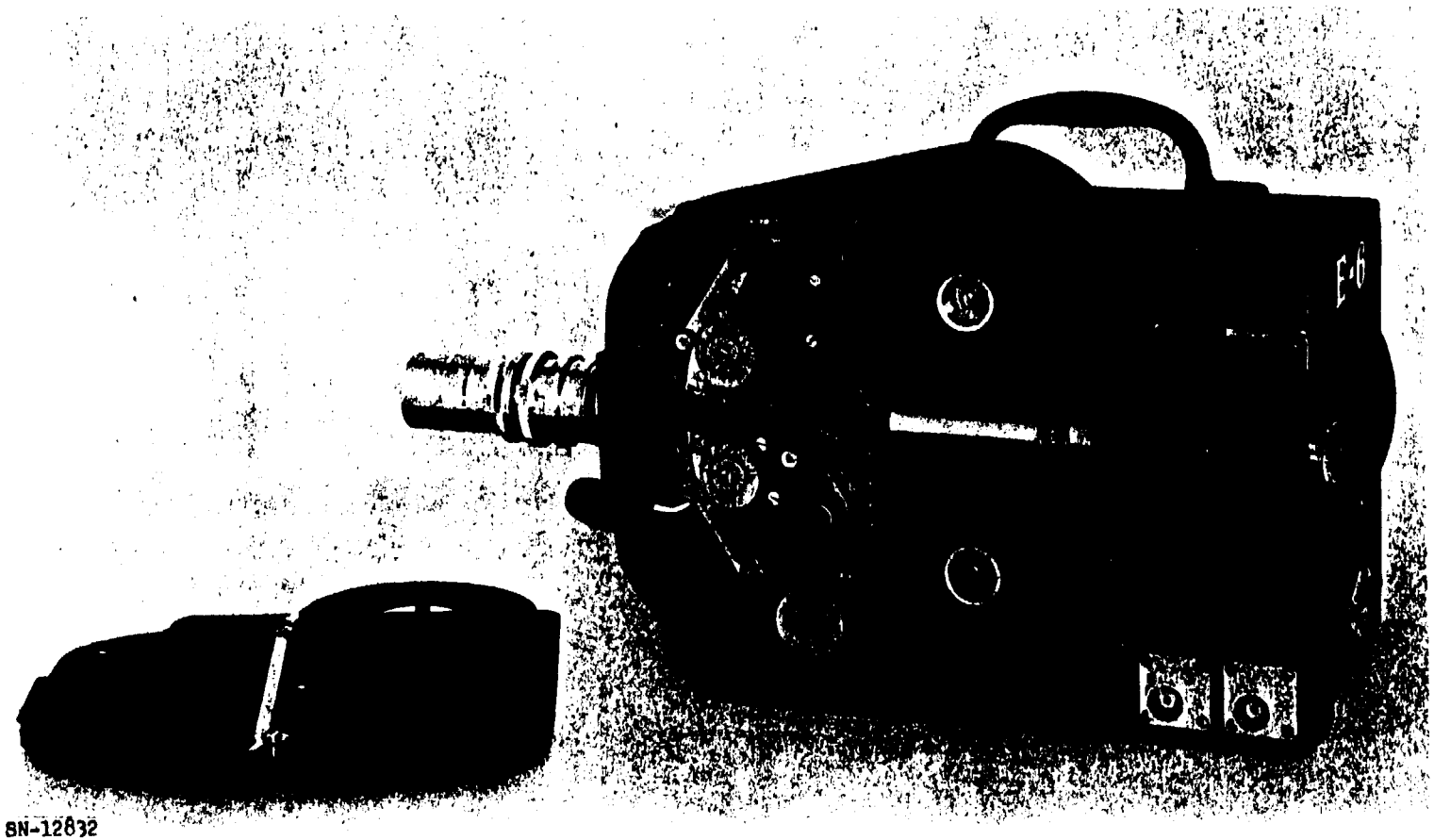

Fig. 4. Eastman high-speed type III camera (cover removed).

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is about 20 percent of the time-interval between successive frames; this improves resolution and smear when rapidly-growing fireballs are photographed. The camera may be run at speeds up to about 3,000 frames per second, and the total running time is less than two seconds. For the Piñon shot we plan to run the cameras at about 2,000 frames per second.

The Eastman camera utilizes a single electrical motor, which drives the film-advance sprocket wheel, the rotating prism, and the take-up spool. Suitable gears are provided to run the prism, and a friction clutch drives the take-up spool. The motor is of the universal ac/dc-type, operating from batteries totaling 120 volts as we use it. The current required is about 40 amperes initially, falling to about 12 amperes at the end of the run. An integral timer removes resistance in the motor circuit as the speed increases, so optimizing the startup time without breaking film under the stress of sudden acceleration. Speed and operating time may be adjusted within limits by choice of initial and final positions of the Ohmite rheostat and also by changing the supply voltage.

The camera is provided with a focusing telescope, arranged to view the image in the film-plane from behind. This accessory is not used for focusing purposes, but does provide a visual check to camera aiming.

10. Lenses

A series of lenses is available for use with the Eastman High-Speed camera, ranging from 25 mm to 500 mm in focal length. The distance from the mounting flange to emulsion is 1.489, ±0.001 inches. The presence of the rotating prism requires that the back focal distance (from rear element to film-plane) be at least 0.495 inches, and further introduces distortion when lenses of very short focal length are employed. In fact it is always necessary to correct for distortion effects whenever lenses shorter than 40 mm are used.

It has been seen that the Piñon fireball might grow to a diameter of approximately 2,700 meters, at the end of the useful portion of the growth. If we place the camera 100,000 ft from the burst, and if we ask that the image of the 2,700-meter fireball be approximately 5 mm in diameter, we find that a lens of about 60 mm focal length is needed. We will consequently use the 63-mm Ektar F/2 ciné lens, manufactured by Eastman Kodak Company. The resulting image will be 4.2 mm in diameter, and the overall

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resolution through the entire optical system will be approximately 25 to 30 lines per millimeter.

The lenses are held in special fixed-focus mounts, rather than in the variable-focus mounts provided by the manufacturer. The special mount, shown in Figure 5, is required in view of the close tolerances of resolution and focus that must be met. The mount allows the insertion of shims, of various thicknesses, by means of which the distance from lens to film may be adjusted precisely. Lenses are focused by means of a collimator and resolution target, which are arranged with a light source and the camera as in Figure 6. The shim thickness is chosen to give maximum resolution over the area of the frame. The focal length is then determined by means of a beam-splitting prism, placed between the collimator and the lens. Measurement of the separation of the two resulting images, and of the deflection angle of the prism, gives a figure for the lens focal length that is good to better than ± 0.2 percent. Measurements made over periods of years have shown these focal lengths to remain constant, except for occasional physical damage, to about ± 0.1 percent.

Lenses are always focused in this manner, rather than visually. It has been determined that the position of best photographic focus differs significantly from that for best visual focus.

Facilities will be provided so that the U. N. Observers can check the focal lengths of the lenses at Parry Island. A calibration range will be provided at the foot of the photo tower. A platform will hold the camera in position to photograph an array of photographic (chemical) flash bulbs. The bulbs will be placed about 200 ft from the camera (1,000 focal lengths), and will be activated to give a short burst of light while the camera is operating at rated speed. The Observers will measure the distance from camera to lights, and also the spacing of the array; measurements of the photographic images will verify the AEC figures as to focal lengths. This check will be carried out for each of the four cameras to be used for U. N. purposes.

Since the cameras do not operate at constant speed, means are provided to impress time data upon the film while the detonation is being photographed. The timing marks are derived from a tuning fork and a high-voltage pulser, which cause a spark gap within the camera to discharge 200 times each second. The light from the discharge gives a series of dots

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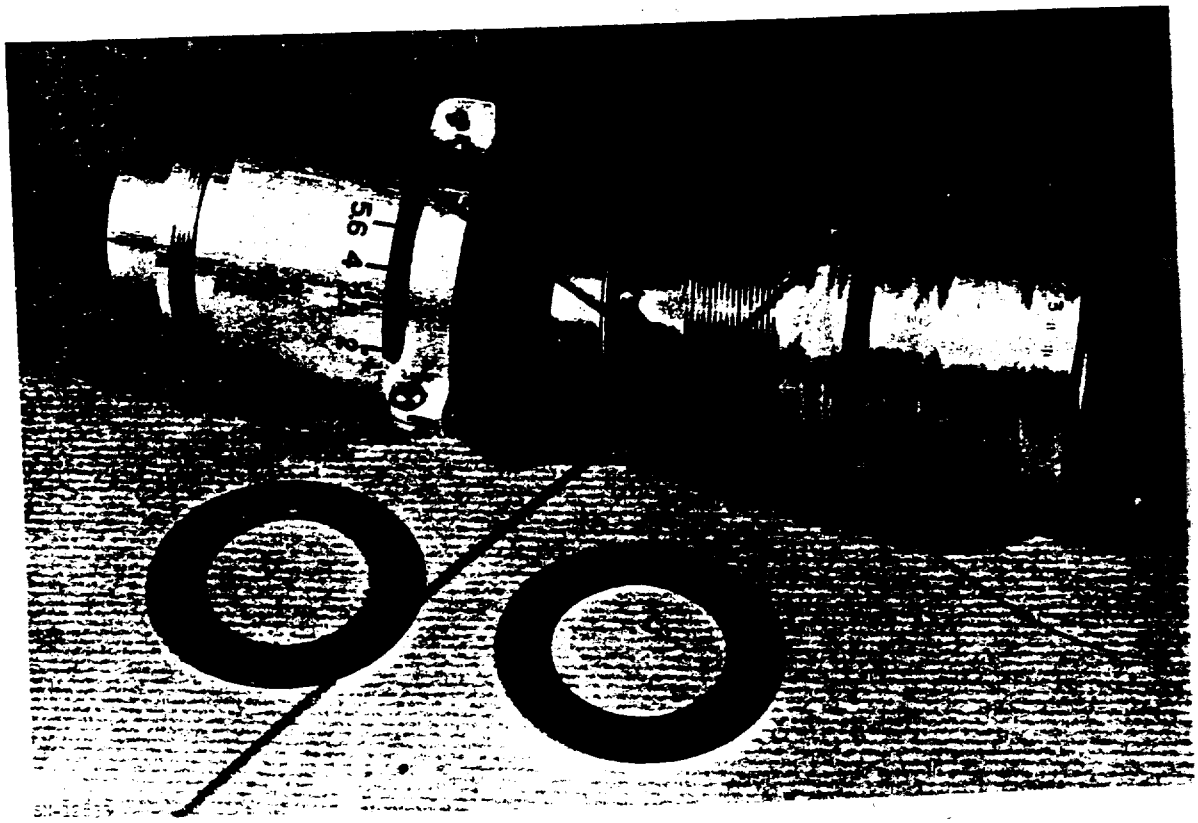

Fig. 5. Ektar 63-mm f/2 lens, special mount and shims.

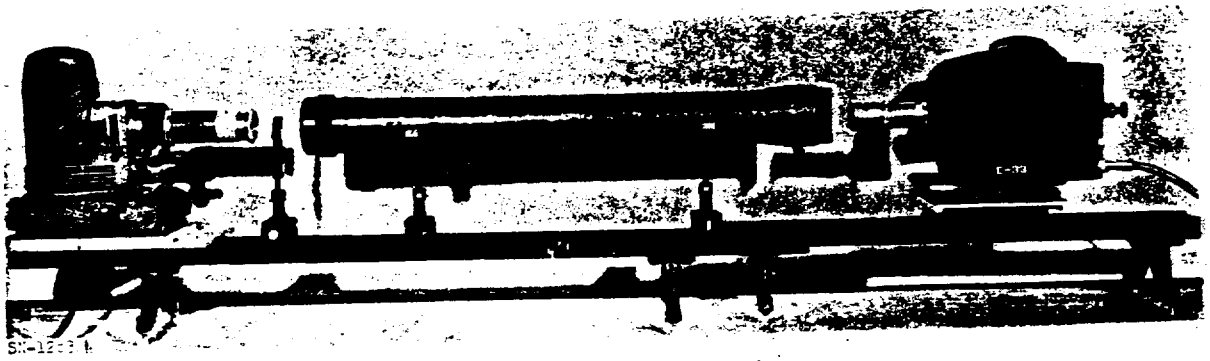

Fig. 6. Collimator setup for focal length measurements.

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along the edge of the film. Each dot is approximately 0.015 inches in diameter, and is located within the frame area of the film rather than between the sprocket holes. The tuning fork maintains its frequency to about one part in 100,000, and the jitter in the individual marks is of the order of one microsecond. Means will be provided for the Observers to verify the frequency of these marks in terms of the velocity of sound in air.

11. Survey Data and Methods

The United States has carried out a first-order survey of the entire atoll over a period of seven years. Benchmarks established around the atoll, and on stations erected above coral-heads within the lagoon, allow precise determination of the location of any new stations within a very short time. A horizontal coordinate grid is used to describe the locations of all stations within the area. The origin of the coordinate system is at a coral-head known as "Oscar"; the geographic location of Oscar is at

N 11° 32' 20.254"
E 162° 17' 10.944"

and the local grid coordinates in feet, are

N 100,000.00
E 100,000.00 .

In this coordinate system, the photo station on Parry is at

N 54,195.00
E 133,085.00 .

The shot barge is expected to be within the rectangle

N 138,500 ± 1,500
E 74,400 ± 2,500 ,

and the exact coordinates will be surveyed after it is in place.

The horizontal distance from camera to bomb is then found simply by subtracting to get the north and east differences, and taking the square root of the sum of the squares.

Clearly it is not practical to check the first-order survey in a matter of a few days, nor is it necessary to check to such precision. The following procedure will be used to permit the U. N. Observers to check the survey results.

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After the shot barge is in place the Observers will measure angles, by means of a Wild T-2 phototheodolite on the barge, between a number of identifiable islands. Furthermore an aerial photograph will be taken, including the barge and a grid of buoys, and also some of the easily identifiable islands in the vicinity.

From the measured angles, and with the help of the aerial photograph, the Observers will spot the barge on two charts of the atoll, and will simply scale the distance to the Parry photo tower from the charts.

Two published charts are available: the first was published by the Japanese Government in 1943, and the second by the United States Navy in 1944 (Hydrographic Office, Chart No. 6033). Although these charts differ by about one-half mile as to the absolute geographic latitude and longitude of the Eniwetok Atoll, and although some of the islands have changed shape markedly from erosion and deposition, distances between given points scaled from the two charts generally agree to better than 0.5 percent.

Scaled measurements from the USN Hydrographic Chart, and from a photostatic copy of the Japanese map, show very good agreement between the two. Three pieces of information are available to establish the scales of each chart: a) scale of distances (nautical miles in the U. S. chart and kilometers in the Japanese), b) distance between parallels of latitude 10-minutes apart, and c) distance between parallels of longitude 10-minutes apart. We know from the standard navigational literature[7,8] that 10 minutes of latitude, centered at latitude 11°-30', is 60,483 feet, and of longitude 59,657 feet. Scaling from the charts gives scale factors in feet per inch for the three methods:

Method	U. S.	Japanese
Scale (nautical miles or kilometers)	8,340	8,370
10-Minute Latitude	8,330	8,530
10-Minute Longitude	8,340	8,460
Average	8,337	8,453

[7] U. S. Department of Commerce, Coast and Geodetic Survey, Special Publications Nos. 8 and 241. U. S. Government Printing Office (1949).

[8] N. Bowditch, American Practical Navigator. U. S. Hydrographic Office (1943).

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It is seen that the U. S. map gives data consistent to better than ± 0.1 percent, while the Japanese chart is internally inconsistent to something like ± 1.0 percent.

Scaling on the chart between known islands which retain the same shape on both charts, we get the following ranges in feet:

	U. S.	Japanese	Diff.
North end, Parry - South end, Engebi	100,300	100,100	-0.2%
North end, Parry - Rigili	102,700	102,900	+0.2%
South edge, Eniwetok - center Elugelab	128,700	127,900	-0.6%
Parry tower - Elugelab	114,050	113,950	-0.1%

12. Meteorological Data

The U. S. Air Force, in support of the AEC, will fly weather-sounding balloons shortly before shot time, from Eniwetok Island. These balloons will radio to ground receivers data as to the air pressure, temperature, and dew point as functions of altitude. Although Eniwetok Island is more than twenty miles from the point of burst, it is certain that the meteorological data so obtained represent conditions above the bomb within the prescribed limits of error.

In order that the U. N. Observers may have a check-reading as to air density, the USAEC will provide a mercury barometer and a sling-psychrometer so that these data may be obtained at ground level on Parry Island.

The determination of air density from the given raw data is treated in the literature; tables will be provided to help in the reduction of data.

13. Films

Photography of the Piñon shot will be accomplished by means of special emulsions manufactured by the Eastman Kodak Company. These films are similar to commercial Microfile film, used as a high-contrast, high-resolution material in microfilming documents and records. For the purposes of fireball photography the special Microfile is provided with a Panchromatic, rather than Orthochromatic, spectral response. This film, identified as "like S.O. 918", has a response from about 0.4 to 0.7 microns. The emulsion is very thin, and is coated by machine on standard acetate base; it can also be obtained on glass plates.

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on the emulsion itself, since such markings pass unharmed through the developing process.

14. Exposures

The luminous fireball emits a small fraction of its total energy in the form of visible light. The radiant emittance (surface brightness) of the fireball varies by a very large factor, from the maximum brightness which it obtains early in the explosion until the minimum which occurs approximately at the time the shock front becomes nonluminous. The variation in surface brightness is shown, for a nominal 20-kiloton device, in Figure 2.92 of The Effects of Nuclear Weapons.[9]

The portion of fireball growth which provides the best information, as far as yield-scaling is concerned, occurs just before the minimum in the light curve. It is consequently necessary to choose the camera exposure to give images of good density during this portion of the fireball growth. As a result the earlier stages are heavily overexposed, and are of less precision owing to spreading of the image and halation. For megaton explosions, it has been found that the surface brightness over the period of interest, is of the order 10,000 watts per square meter in the spectral band 0.4 - 0.7 microns. This corresponds to a black-body having a temperature of 2200 to 2500° Kelvin. The equivalent reading of the Weston photographic exposure-meter would be 200,000.

One additional factor to be considered, before exposures and aperture settings can be computed, is the loss of light due to absorption and scattering in the twenty-mile path of air between the fireball and the camera. Obviously one cannot predict just what transmission may obtain at shot time, and it is necessary to allow for a considerable variation. Experience has shown that at best, only 50 percent of the light can penetrate a twenty-mile path, and that unacceptable images result if we have less than 3-percent transmission. To compensate for the variations that may be expected in atmospheric transmission, we will choose different lens apertures for the several cameras; as a result we may have only one film with excellent images, but the probability is that two or three will be usable.

It is expected that no filters will be used on the cameras.

[9] S. Glasstone (ed.), The Effects of Nuclear Weapons. U. S. Government Printing Office (1957).

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15. Processing Films

The special Microfile emulsion is developed in Stineman tanks, using full-strength Kodak D-76 developer at 75°F, for 2.5 minutes. After development the film is placed in a short-stop solution, and then is fixed and washed. Drying is accomplished in air, without forced drying. This procedure results in a gamma between 0.95 and 1.05, and a typical H and D curve, showing density as a function of exposure, is given in Figure 7. The curve is obtained from densitometer measurements on a test exposure of a gray scale, which provides some 21 discrete known exposures.

The film may be processed in a dim medium-green dark-light; it is necessary to dark-adapt the eyes for about twenty minutes in order to see at all while the processing is done. It is possible to retain green-adaption, outside the dark-room, by wearing red goggles; these will be provided for the Observers who may wish to watch the processing operation.

Processing of test films, designed to check exposures and proper density of film-speed markers, will be carried out on Parry by these procedures. Lens-calibration films, and the shot films, will be processed in Berkeley together with gray-scale films to verify the sensitometric control.

16. Duplication of Films

After the original negatives have been analyzed at Berkeley duplicate prints will be produced in Hollywood. The prints will contain portions of the reticle, so that scale factors will be maintained. In the printing process, the exposures will be adjusted to compensate, in part, for the widely varying densities on the original and to preserve the greatest detail possible.

Duplicates of the original reticle will be produced on glass plates, in order to minimize dimensional changes, for distribution to the Observers.

17. Time Signals

The cameras and accessory control equipment will be placed in a cab at the top of a 300-ft tower, near the north end of Parry Island. (Figure 8). Operation of the photographic station is entirely automatic, requiring no operators at shot time.

The master sequence timer, located in the Control Building at the foot of the Parry tower, generates time signals for distribution to all experimenters in the area as well as those needed to ARM and FIRE the bomb.

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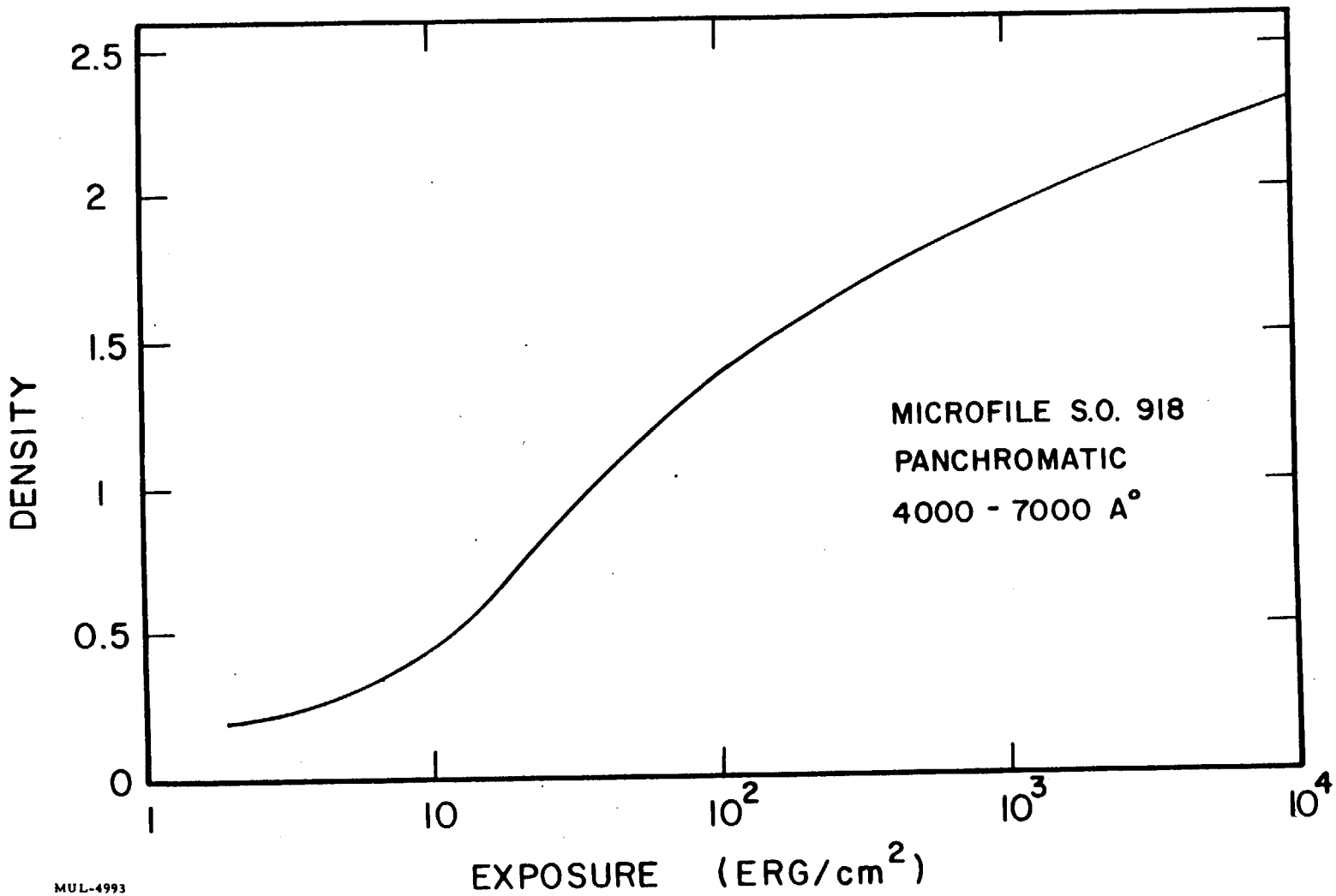

Fig. 7. Density as a function of exposure, Microfile emulsion S. O. 918, panchromatic 4000 - 7000 Å.

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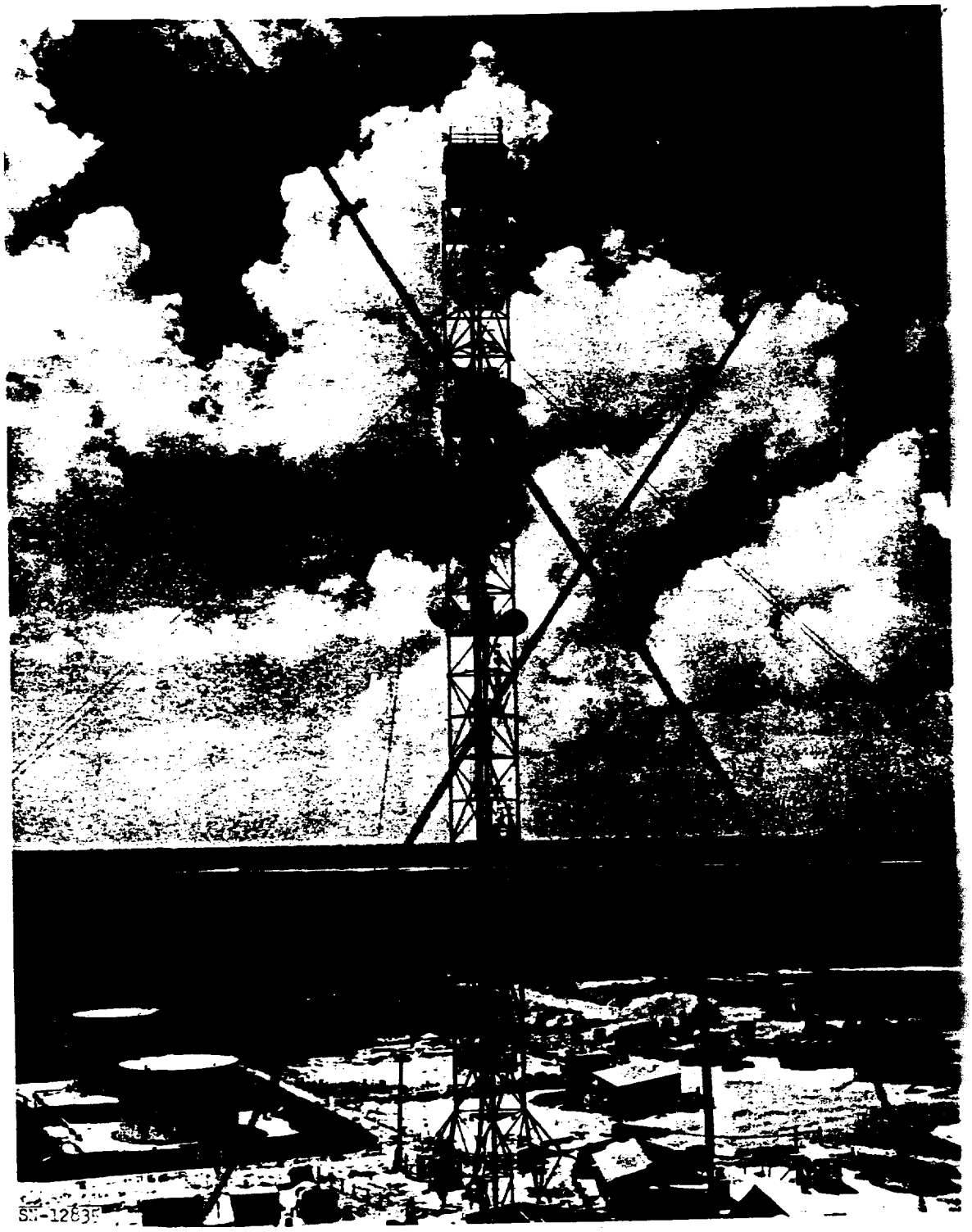

Fig. 8. Three-hundred foot photographic tower, Parry Island.

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These signals are used, in the photo station, to open the rolling door of the cab, to apply power to electronic equipment, and finally to start the cameras themselves. Each signal is sent at a definite time relative to the FIRE signal to the bomb; the several signals are precise to something like ± 0.05 seconds.

The sequence of signals used in the photo tower is:

- 15 minutes: Apply filament power to electronic equipment
- 1 minute: Open cab door
- 15 seconds: Apply plate power to electronics
- 1.5 seconds: Apply power to Eastman camera motors
- 0 seconds: Test signal (for dry runs only)
- + 1 second: Remove power and deactivate station.

The photography for determination of yield is a prime measurement; failure of the photo station in any respect is considered grounds for postponing the shot. Consequently an interlock switch, activated by the photo station, will be inserted in the FIRE line, and the bomb will not be fired unless: a) the cab door is open,

b) the film-speed markers are pulsing, and

c) power is applied to the camera motors.

To maximize the reliability of station operation, the installation will be operated as if it were two separate, independent stations. Two sets of timing signals will be supplied from the control room. Each signal set will operate three Eastman cameras and independent electrical circuits. Each of the two "camera stations" will provide an interlock signal, and the two interlock switches will be connected in parallel. As will be seen, four of the six cameras are to be operated for the U. N. program; the other two are for AEC purposes.

To assure proper operation at shot time, it will be necessary to have a simulated dry run, which will duplicate as nearly as possible the intended operation at shot time. For the dry run the station will be set up and checked out, exactly as planned for the shot itself. Operators and Observers will stand within the cab to see that everything works properly, but they will not be permitted to throw switches or to interfere in any way with the automatic working of the station. The films will be developed at Parry, and will be inspected to see that the film-speed marks are of adequate

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density and readability, and that the cameras were running at the proper speed at zero time.

As a general rule we would need more than one dry run to prove out the operation of a station. However, the Parry station has been running throughout Operation Hardtack, and is already proved out; it will only be necessary to verify operation for the satisfaction of the U. N. Observers.

18. Equipment Protection

Two natural hazards must be considered in designing a camera station such as that established at Parry; these are rain and corrosion. The distance from the detonation is great enough that no problems are expected from shock, thermal radiation, or from nuclear radiations.

The climate in the Marshall Islands is humid at all times, and heavy rain squalls of short duration may occur at any time. Further hazards arise from the corrosive action of salt-laden air, and from living fungus organisms. The remedies for these activities can only be preventive, and lie in the proper choice of materials resistant to them, and of shelters capable of withstanding the driving rain.

The photographic equipment is housed within a cab at the top of a 300-ft tower on Parry Island. Each camera is placed on a tilting/locking table, which is supported on a vertical shaft. The arrangement, which is shown in Figure 9, is similar to that employed on drill presses. By this means it is a simple matter to swing cameras in any direction for aiming purposes, to tilt them as required, and finally to lock them in position. Two such columns will be employed, each carrying three Eastman cameras. The electrical accessory equipment will be mounted in standard relay racks; each unit employing high voltages is sealed tightly to keep moisture out. Power for the cameras is obtained from a bank of storage batteries placed in the cab; power for the accessories comes from the Parry Island a-c distribution system.

The roof of the cab has been made water-tight by applying pitch as required. The northern wall of the cab is a roller door, similar to those used on garages; the door is normally closed, and is opened by means of an electric motor when the -1 minute signal is received. It is closed automatically after the last camera runs out of film.

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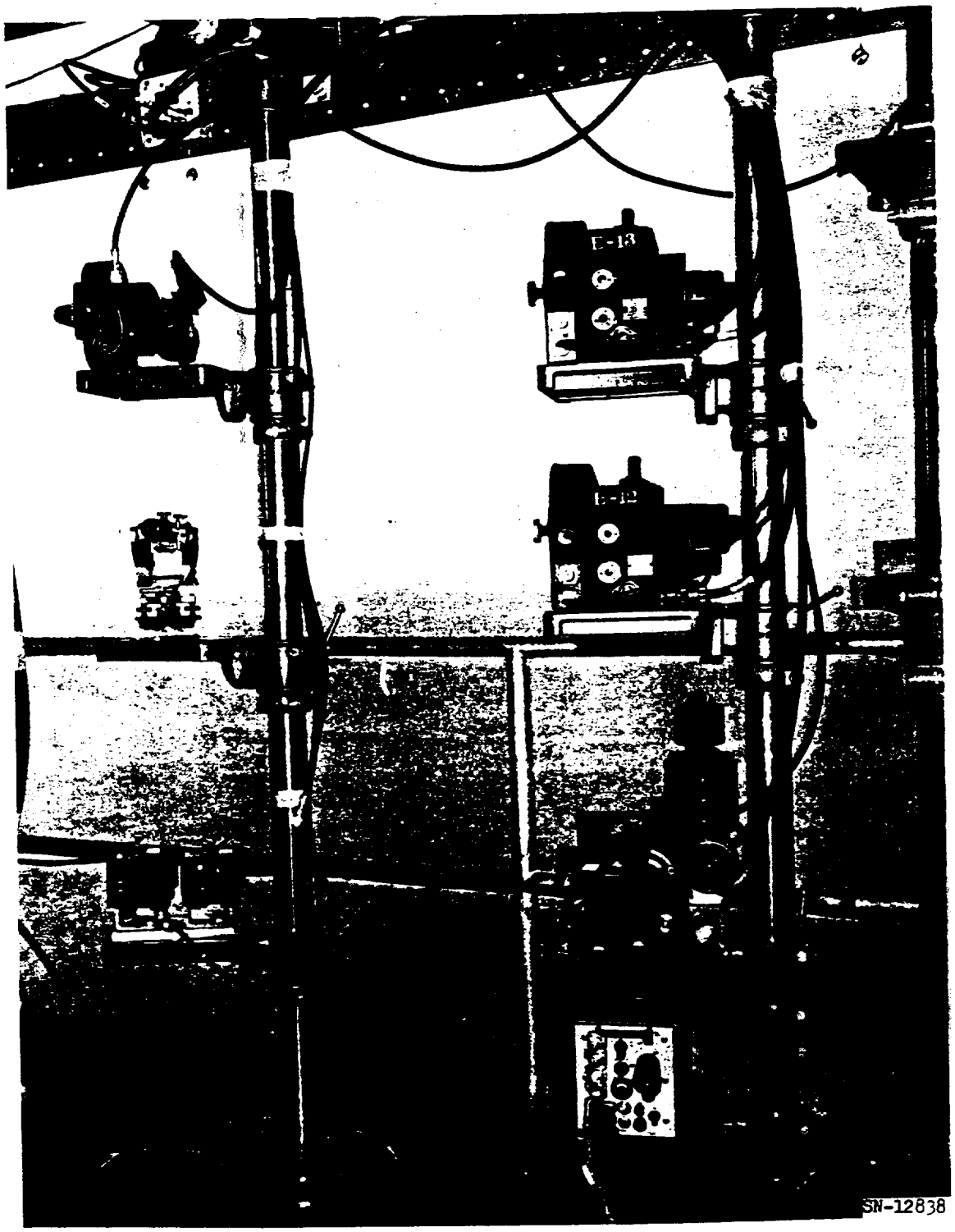

Fig. 9. Camera mounts in Parry Island tower.

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19. Rain Radar

Although the photographic plan is designed to accommodate a considerable variation in the transmission of light through the atmosphere, it is clear that satisfactory photography cannot be accomplished if a rain squall moves into the line of sight. As a means of assuring a clear view, a 3-centimeter radar set has been provided at the Control Building; the antenna is mounted in the photo tower, at the 40-ft level. With this equipment it is possible to observe the locations of rain storms within 50 miles of the radar. Repeated observations determine the speed and direction of the drift of these storms, and enable us to predict their locations up to an hour in advance. On the basis of these predictions it is possible to say that one given time will be unacceptable, or that an alternate will be preferable; these predictions are made far enough ahead of time to choose a suitable firing time and to get the information to participating aircraft and other manned stations.

20. Aiming and Tilting of Cameras

Cameras are aimed visually whenever possible. It is sometimes impossible to see the shot barge from the photo tower twenty miles away, even with the aid of telescopes, because of poor atmospherics. Recourse is usually taken to aiming at night, by means of a distinctive light placed on the barge. Occasionally even this method cannot be used, and aiming is accomplished by sighting on a known nearby object or island, and swinging the camera through an angle computed from the survey data. In such cases it is good enough to measure the angle to about 0.5 degrees, placing the image within 0.5 mm from the center of the frame.

In order to utilize the entire film area, and to record the largest practicable images, it is desirable to elevate the camera through a tilt angle, τ. This angle is usually chosen to place the horizon about 15 percent of the distance from the bottom to the top of the film frame. For the Eastman camera, with a vertical frame dimension of 7.4-mm and using a 63-mm lens, the tilt angle is about 2°-10'. The angle is set by tilting the mounting table, and measuring the angle with an inclinometer.

21. Photo Plan and Check Lists

The evolution and execution of the photographic effort is controlled

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and documented by means of printed forms and check lists. Typical forms worked up for the Piñon shot, are given in Figures 10 and 11. The Photo Plan sheet is used to outline the photographic effort contemplated for a given shot; as details become available these are added to turn the sheet into a detailed instruction sheet from which the entire station may be established. A separate sheet is prepared for each station to be used; for Piñon there is only one such station.

The Photo Loading Chart (Figure 11) gives instructions as to the type of film and identifying number, which is perforated through the film base, and also information as to exposures and settings. In addition, the Loading Chart provides a running record as to the status of the film-load, indicating how long it has been in the camera, and when it needs to be replaced.

The station is set up according to these charts, and is tested in several simulated dry runs. The dry-run films are processed and are examined to be sure that exposures are correct, that speed-marks have been placed on the film at proper density, and that the cameras operate at the specified speed for the prescribed time interval.

A day or two before the shot, the final film is loaded into the cameras, and the station is carefully checked out by two operators who use a master check list. Sample check lists are presented in Appendix I and II at the end of this chapter to show the sort of information that is checked, double-checked, and certified by signature of the operating crews. Of course it is necessary to check the check lists during dry runs, to assure their complete adequacy.

In the event of postponements for a day or two it is customary to turn the cameras over by hand, to advance a few feet of film through the camera gate. This eliminates the effects of sharp bends and loops, which might take a permanent set and which might break during the sudden acceleration of the camera. In case the postponements are repeated for five days or longer it is customary to replace the entire station film-load.

22. Analysis Equipment

The analysis program embraces the reading of calibration films and the determination of focal lengths, the reduction of survey data and the calculation of magnification factors, the reading of fireball images and the calibration of the optical systems employed, the determination of the tim

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PHOTO PLAN

STATION NO. 1511 PARRY
STATION TYPE 300' TWR
DISTANCE GZ ~100,000'
DISTANCE OBJECT

EVENT PIÑON
GZ STA. S.E./ENGEBI
DATE MAY 1958
POSTED LF

	STATION	GZ	DIFF.	TILT
N	54,195	~138,500	~83,800	GZ
E	133,085	~74,400	~58,700	OBJ
Z	300	~10		

CAMERA			LENS			FIELD TARGET	AIMING			POWER			MARKER		DELAY	FILM	PURPOSE	REMARKS
NO	NOM SPD	RACK POS.	FOC. MM	S/N	FILTER	H/V	OBJECT	H	V	VOLTS	SHUT RHEO	TIME ON/OFF	TYPE	S/N				
E-	2000		63		NONE	14.5/9.5	GZ	0°00'	2°10'	120	30/60	-1.5/+1.5	200		NONE	MF	UN	"A" SIGNALS
E-	"		"		"	"	"	"	"	"	"	"	"		"	"	"	"
E-	"		"		"	"	"	"	"	"	"	"	"		"	"	"	"B" SIGNALS
E-	"		"		"	"	"	"	"	"	"	"	"		"	"	"	"
E-	"		"		"	"	"	"	"	"	"	"	"		"	"	AEC	"
E-	"		"		"	"	"	"	"	"	"	"	"		"	"	"	"A" SIGNALS

REMARKS INTERLOCK STATION

FOUR UN CAMERAS: CALIBR. AND SHOT FILMS WILL BE PROCESSED AND ANALYZED AT BERKELEY
TWO AEC CAMERAS: PROCESS AND ANALYZE ~~AT PARRY~~ IMMEDIATELY

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Fig. 10. Typical form for Piñon shot - photo plan.

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PHOTO LOADING CHART

STATION 1511 PARRY EVENT PIÑON DATE

FILM					CAMERA			LENS		EXPOSURE			REMARKS LF
TYPE	EMULS. NO.	SIZE	HOLDER	PERF. NO.	NO.	RACK POS.	NOM. SPD.	FOC. MM	FILTER	APER.	SHUTTER RHEO.	W/M²	
MF		16/100	SPOOL		E-		2000	63	NONE		30/60		
"		"	"		G-		"	"	"		"		
"		"	"		E-		"	"	"		"		
"		"	"		E-		"	"	"		"		
"		"	"		E-		"	"	"		"		DEVELOP PARRY
"		"	"		E-		"	"	"		"		" "

DATE FILM LOADED _____ DATE CAMERA LOADED _____ DATE EXPOSED _____

REMARKS _____

MUL-4995

Fig. 11. Typical form for Piñon shot - photo loading chart.

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after detonation at which each frame was exposed, and finally the calculation of the yield and of statistical confidence limits.

The basic measurements from the films are accomplished by means of a Profile Measuring Microscope, Model P219, manufactured by Henri Hauser S. A., Bienne, Switzerland. This instrument is illustrated in Figure 12, and is most frequently termed the Comparator.

The film is placed upon the lower stage, which may be translated in orthogonal directions by means of two micrometers. Each micrometer may be read, by means of a vernier, to 0.0001 inch; motion of the stage is limited to 2 inches in each direction and it can also be rotated. The stage may be raised or lowered to attain critical focus by means of the large hand-wheel at the lower right. The film is observed through the eyepiece, by means of an objective lens. Several interchangeable objective lenses are available, ranging from 6X to 50X.

A special jig has been built to hold the film reels; the portion of film under investigation is held flat against the stage by a glass plate. The film is illuminated from below by means of a light bulb whose brightness may be adjusted with a rheostat. This adjustment is particularly useful since the films vary tremendously in density.

An additional feature of this instrument is the second stage, located at the top of the comparator. By means of a knob one can superimpose images from the two stages, that from the upper stage being reduced in size to one-tenth. Thus, in the toolmaker's use of the instrument, a piece of work may be compared directly with a ten-times drawing, to observe minute deviations in the work.

For the purposes of fireball reading a grid of concentric circles is placed in the upper stage; the diameters of these circles are calibrated through the optical system in terms of the micrometers of the lower stage; and the fireball diameters are estimated in terms of the calibrated circles. Figure 13 shows the circular grid which is provided as a transparency of glass.

In order to calibrate the instrument it is only necessary to place a knife edge or razor blade on the lower stage. The edge is aligned with one of the larger circles, and the micrometer reading is noted. Then, using the micrometer to move along a diameter, the edge is aligned with the other side of the same circle, and a second reading is taken. The differen

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Fig. 12. Hauser profile measuring microscope, Model P219.

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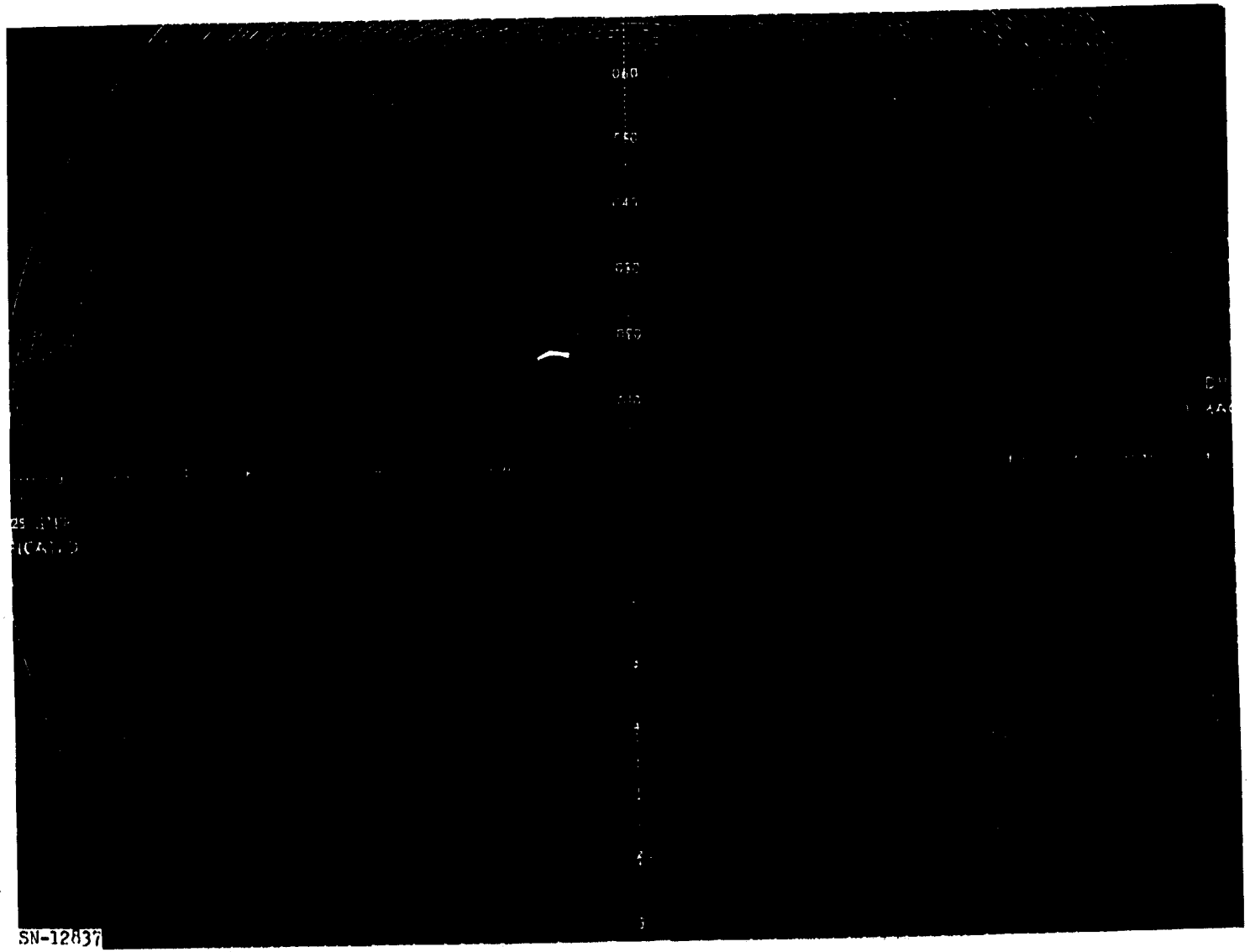

Fig. 13. Circular grid for fireball measurements.

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between the two readings is the lower-stage distance corresponding to the given circle. The Observers may, if they wish, similarly calibrate other circles to assure themselves of the linearity of the device.

It is customary to approach each reading from the same direction, to eliminate any backlash that may be present. Similar calibrations are required for each of the objective lenses that may be used. It will probably only be necessary to use the 30X and 20X lenses.

To prevent damage to the irreplaceable films, very careful handling is required at all times. Nylon gloves are worn to prevent fingerprints and body oils, which can penetrate the emulsion and serve to catch dust particles. The glass plate, which holds the film flat on the lower stage, is lifted by means of a locking attachment to permit drawing the film through freely and without scratching.

23. Choice of Frames to be Read

Referring to Figure 3 (Section 4.) of this chapter, it is seen that regular (constant-ϕ) growth useful for scaling purposes may extend from about 70 to more than 300 milliseconds. Over this interval each camera will expose more than 450 pictures, at a rate of about 2,000 per second. This many pictures are needed to establish the time-scale to adequate precision; however, it is clearly unnecessary to measure all of them. Indeed it will be more than adequate to measure only one frame in ten, and in some cases one frame in twenty should suffice.

Since the film-speed marks are placed at a rate of 200 cps, it will greatly simplify the analysis procedures if we choose to measure only those pictures that occur beside the speed marks. An auxiliary measurement of the position of the mark relative to the frame then suffices to establish the time after detonation at which the frame was exposed. This procedure is more than adequate for large bombs, and is much simpler to accomplish than the rigorous method of measuring the varying distance between successive marks, drawing the acceleration curve for the camera, and integrating numerically to evaluate the time after detonation for each frame of interest.

24. Evaluation of Image Diameters

The measurement of an ideal spherical image, with sharp edges and good contrast, is a simple exercise. Unfortunately such images are

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encountered infrequently. For the Piñon shot the images will be approximately hemispherical. The fireball edge will be only moderately sharp, because of scattering in the 20-mile photographic path; scattering may also result in poor exposures of low contrast. Furthermore, natural clouds will probably obscure portions of the fireball, since it will grow to a considerably greater height than the normal low-lying cloud cover. These factors introduce the necessity for exercising some degree of judgment in measuring the fireball diameters.

The orientation of the film on the comparator stage is such that the images will appear to be on their sides, with the horizon vertical. The image of the selected picture is centered, making use of the micrometers and the rotational adjustment, so that the base of the fireball coincides with the vertical diameter of the circular grid pattern. It will undoubtedly be necessary to adjust the illumination for both stages, and in some cases to switch the upper stage light on and off to aid in locating the fireball edge in reference to the grid.

The observer can usually bracket the average diameter quickly by noting the greatest and the least circles of contact. These limits can be narrowed by running the eye around the intermediate circles, finally interpolating to arrive at a best estimate of the average or effective diameter. Experience and practice are required to make this determination quickly and consistently, and without undue fatigue. It is always best, in our experience, to have each picture measured by several persons; in the event of disagreement between them a short discussion usually suffices to reach a joint reading agreeable to everyone.

Before moving the film to read another frame, it will be necessary to measure with the micrometer the distance from the film-speed mark to the trailing sprocket hole. These measurements only need to be precise to about 0.03 inches, or one-tenth of a frame, and a visual estimate may suffice instead of a measurement. They will enable the calculation of the time for the particular picture.

25. Calculation of Total Yield

Measurements and calculations are best worked out in tabular, systematic form. We usually record all measurements and calculations on vellum, which may be reproduced in any desired quantities easily and

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quickly. One sheet of paper will summarize the magnification parameters:

horizontal distance: L
camera tilt: τ
optic-axis distance: $L \cdot \cos \tau$
camera focal lengths: f
camera magnifications: $L \cdot \cos \tau / f$, and
the Hauser magnifications for each objective.

Another sheet will summarize the meteorological data, and will tabulate air density ρ_z and the fifth-root of the density, as functions of altitude; the fifth-root data will also be plotted on graph paper against altitude.

Four additional sheets, one for each film, will tabulate for each picture measured:

the time and image diameter,
the corresponding object diameter, D
the parameter $\phi = D \cdot t^{-2/5}$, and also
$\phi \rho_z^{1/5}$.

Tables giving $t^{-2/5}$ as a function of t, will be provided to aid these last two determinations, and the density chosen will correspond to an altitude equal to one-fourth the diameter.

The computed parameter ϕ will be plotted against log (time) to determine the interval over which it is essentially constant. Finally an average figure will be determined for $\phi \rho_z^{1/5}$, over the indicated time interval and over all four cameras; this value will be raised to the fifth power and multiplied by $\frac{1}{2} \times 1.272 \times 10^{-8}$ to obtain the total energy release in kilotons.

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APPENDIX I. SAMPLE CHECK LIST No. 1.

EASTMAN HIGH SPEED CAMERA

Check List

SHOT _____

Station _____ Live Run _____

Date _____ Dry Run _____

Checker _____

1.	Camera aimed.				
2.	From loading data sheet				
	a. Filter				
	b. "F" Stop				
3.	Lens Cap Off				
4.	Camera loaded				
5.	Film shoes in locked position				
6.	Secure cover				
7.	Turn rheostat to zero				
8.	Set motor cutoff switch at 100. Listen for Microswitch click				
9.	Set rheostat _____/_____				
10.	Close eyepiece				
11.	Connectors tight				

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APPENDIX II. SAMPLE CHECK LIST No. 2.

PHOTO STATION GENERAL ELECTRICAL FINAL CHECK LIST, EG&G.

Shot _____ Location _____ Date _____

1. Visually check all Connectors. _____
2. Throw the following switches to OFF position: S1R _____
   S6R _____
   S1B _____
   S1Y _____
   Charger # 1 Input _____
   Charger # 1 Output _____
   Charger # 2 Input _____
   Charger # 2 Output _____
3. Throw the following switches to ON position:
   Gas Generator AC _____
   24 V DC _____
   120 V DC A _____
   120 V DC B _____
   200 CPS (R) 2 Switches _____
   200 CPS (B) 2 Switches _____
   200 CPS (Y) 2 Switches _____
4. Throw change-over switch to MG position.
   (Check that this switch is securely in position) _____
5. Throw MG Test Toggle Switch on Inverter Starting Panel to ON Position. MG SHOULD NOW BE OPERATING. _____
6. Check that the following voltages appear on the Distribution panel:
   120 V AC _____
   120 V DC A _____
   120 V DC B _____
   24 V DC _____

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7. Throw MG Test Toggle Switch on Inverter, starting panel to OFF position. MG should now STOP. _____

8. Throw S2, S3, S4, S5, S7, S8, S9, S10 on each Control Panel to TIMER position. Red panel _____

   (If camera is not being used on this shot, leave its switch in OFF position) Blue panel _____ Yellow panel _____

9. Install fuse wire and set camera curtain in Position _____

10. Signal cable in position _____

11. Generator cutout cable in position, Switch on. Generator is in Electric Start position, and generator running. _____

12. Gas generator power cable in position _____

13. Check that all timers are in START position _____

    M1R _____

    M2R _____

    M1B _____

    M1Y _____

14. Set heater _____

15. Install necessary chocks at trailer and generator _____

16. Remove rear platform. _____

17. Check that vehicle canvas tops, doors and windows are properly set. _____

18. Secure loose objects. _____

SIGNATURE _____

CHAPTER III

RADIOCHEMICAL DETERMINATION OF FISSION YIELD

A. THEORY

The fission yield of a device can be measured by radiochemical techniques by using macroscopic tracer of sufficient amount to allow a measure of the fraction of total debris collected in a sample. From this bomb fraction and the absolute number of fissions collected in a sample, the total fission yield can be measured.

The bomb fraction tracer is placed in such a manner as to insure that the material will mix completely with the fission products and be distributed uniformly with the fission products throughout the post-shot cloud. Aircraft equipped with units designed to collect representative samples of debris on filter papers are flown through the cloud.

The samples are removed from the aircraft by remote handling techniques, the radiation levels measured and the samples packaged and returned to the laboratory for dissolution and analysis. Fractions of the solution containing the filter paper are then taken for measurement of the bomb fraction and the absolute number of fissions. Uranium in the form of U_3O_8 is used as the tracer. Molybdenum 99 has been chosen as the fission product to be determined. The total fissions are given by

$$\text{Total fission} = \frac{\text{Initial uranium}}{\text{Uranium in sample}} \times \text{Fissions in sample.}$$

Since one megaton TNT equivalent is defined as 10^{15} calories and the prompt energy per fission is 179 Mev, 1.45×10^{26} fissions are equivalent to one megaton.[10]

B. TECHNIQUES

REVIOUSLY ELETED

1. Bomb Fraction Tracer

The bomb fraction tracer to be used is [redacted] uranium partially depleted in U^{235} in the form of uranium oxide (U_3O_8). The uranium oxide has a bulk density of about 2.5 g/cc and will be packaged in approximately 100-pound containers.

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[10] R. B. Leachman, Phys. Rev. 87, 444 (1952); R. B. Leachman and W. D. Schafer, Can. J. Phys. 33, 357 (1955); and S. R. Gunn, H. G. Hicks, H. B. Levy, and P. C. Stevenson, Phys. Rev. 107, 1642 (1957).

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nitric acid may be required to keep the reaction under control. As long as the addition of concentrated nitric acid produces noticeable nitrogen dioxide fumes, small additions are made periodically.

e. When the reaction is complete, the mixture is fumed down to approximately 20 ml, cooled, and 20 ml of 6 normal hydrochloric acid is added. The beaker walls are rinsed thoroughly with the hydrochloric acid and the solution diluted with one-half volume of water and cooled.

f. The contents of the beaker are filtered through fine filter paper to remove any solids, and the filter paper washed with a few ml of 6N hydrochloric acid.

g. The filter is transferred to the Vycor beaker and wet-ashed with 50 ml of concentrated nitric acid and 30 ml of concentrated perchloric acid. The solution is then evaporated until fuming begins.

h. The solution plus any precipitate is transferred to the platinum crucible, and the beaker washed with 2N perchloric acid. Five ml of concentrated hydrofluoric acid is added and the solution fumed to heavy fumes of perchloric acid for several minutes. The solution is cooled, and 6N hydrochloric acid is added. The solution is then transferred to a 40-ml centrifuge tube and centrifuged.

i. Any residue remaining after this step (usually there is none) is subjected to a sodium carbonate fusion using 1 gram of sodium carbonate and fusing for 10 minutes at 900 - 950 °C.

4. Uranium Analysis of Filter Paper Samples

a. Introduction. Since the observation by Nichols and Slattery in 1926[11] that small amounts of uranium fused in sodium fluoride give an intense yellow fluorescence, measurement of this property has been widely used for the quantitative determination of uranium, particularly in the 0.001 to 1 microgram range. Reference should be made to the reviews of Rodden,[12] and to the reasonably comprehensive article of Price, Ferreti and Schwartz[13] for detailed information in regard to this determination and

[11] E. Nichols and M. K. Slattery, J. Opt. Soc. Amer. 12, 449 (1926).

[12] C. J. Rodden and J. C. Warf, National Nuclear Energy Series, Div. VIII, 1, "Analytical Chemistry of the Manhattan Project", McGraw-Hill, pp. 122-135 (1950).

[13] G. R. Price, R. J. Ferretti and S. Schwartz, Anal. Chem. 25, 322 (1953).

for references up to 1953 to the rather extensive literature concerning this method.

b. Interference by Fluorescence of Other Elements. In the carbonate-fluoride flux employed, the fluorescence of uranium excited by 3600 Å light is for all practical purposes a specific property and the method is essentially free from interference by other elements. The article of Price, Ferreti and Schwartz includes specific references and data in regard to this aspect of the method. In all steps of the procedure great care is taken to eliminate the possibility of error from fluorescent organic compounds.

c. Interference by Quenching. Much more important for the application of the method is the fact that many ions will decrease or "quench" the fluorescence of uranium when they are present in the flux above certain threshold amounts. Thus, for example, amounts of iron up to approximately 10 μg in a 0.3 g flux show no effect on the fluorescence, but above this amount the fluorescence is quenched and is reduced by almost 50% in intensity when the amount of iron reaches approximately 100 μg. Fortunately, no element has been found to quench significantly in amounts less than 1. to 0.1 μg and microgram amounts of many substances can be tolerated. In a general way then, it can be said that if the amount of uranium determined is 0.1 μg or less no significant quenching will be observed for any element present in amount equal to that of the uranium. To prevent quenching, by separation of the uranium from interfering elements, it is therefore only necessary to adopt procedures that bring the weight of the most critical quenchers to the same level as that of the uranium. In the procedure given below this separation is made by extracting the uranium, present as uranyl ion in saturated aluminum nitrate solution, into an approximately equal volume of ethyl acetate.

As an alternative to this separation procedure, consider the amounts of the possible interfering elements expected to be associated with the uranium. If the amounts accompanying 0.1 μg of uranium fall in order of magnitude below the threshold quenching amounts, it is possible to transfer directly to the fusion step without separating the uranium. The reliability of this approach is somewhat uncertain due to the possible introduction of quenching elements present as impurities in the rather large amounts of reagents required to dissolve the filter paper samples. Because of the

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latter factor, the direct determination of uranium in a sample aliquot may conveniently be used to obtain an approximate bomb fraction value. Such results must be confirmed by determinations that employ the separation procedure.

d. Contamination. Since the final amount of uranium determined is on the order of 0.1 to 0.01 μg it is essential to run a blank involving all reagents to provide a correction for the small amounts of uranium they may contain. It is also essential to be particularly on guard against accidental introduction of uranium in all operations. Errors due to the latter factor are quite variable and can be checked by considering the precision of parallel determinations.

e. Present Application. In the determination of the very small quantities of uranium collected from the cloud that are to be used to measure the bomb fraction present, it is pertinent to consider the quantities of uranium involved compared to that of all other substances which are likely to be present and may interfere in the analysis. The uranium present in the initial bomb is far outweighed by the uranium tracer placed on the barge and can be ignored in the analysis. The most massive element present in the barge is iron. An explosion in the megaton range can be expected to carry large amounts of sea water into the bomb cloud, presumably well mixed with all other bomb debris. The fluorescence method of uranium analysis takes advantage of the extreme sensitivity and specificity of this measurement.

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Table I gives an estimate of the micrograms of other elements initially present with 0.01 μg of U^{14}. Only the elements listed above boron are expected to be present in equal or larger amount. Interference by quenching from calcium, manganese, lead, chromium and iron is not to be expected since their estimated amounts are too low by a factor of 10^2 for iron, 10^3 for calcium and still larger factors for the others. The amount of uranium in the individual sample is expected to be about 100 μg.

Table I

Element	μg present/0.01 g U
U (tracer)	--
Fe (barge)	0.1
Cl	9.
Na	5.
Mg	0.6
S	0.45
Ca	0.2
K	0.2
Br	0.035
C	0.015
Sr	0.006
B	0.0025
Si, F, Al, Ru, Li	<0.0012
P, Ba, I, As, Fe	<0.00005
Mn, Ca, Zn, Pb, Se	<0.000005
U (sea water)	0.000075
Others	

5. Procedure for determination of Uranium

a. Evaporation Step. Take an accurately measured aliquot of the solution of the filter paper sample chosen to contain approximately 2 μg of

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uranium and transfer to a 50-ml round bottom flask. Evaporate carefully to fumes of perchloric acid. Add 5 ml of concentrated nitric acid and again evaporate. Repeat this step to insure the removal of chloride and the oxidation of all organic matter.

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b. Extraction Step. Add 5 ml of saturated aluminum nitrate solution to the residue in the flask. Add 5.00 ml of reagent-grade ethyl acetate and thoroughly mix the solutions for about a minute using an electrically driven stirrer or a rod extractor. Allow the layers to separate.

Recovery of the uranium in this step is known to be 90% or better and removal of quenching elements is known to be reliable.[15]

c. Fusion Step. Pipet 50- to 250-microliter portions of the ethyl acetate layer to clean platinum dishes. Choose volumes that will yield an estimated 0.05 to 0.1 μg of uranium. Place the dishes on graphite blocks and carefully evaporate to dryness.

Add about 300 mg of the flux to each dish. A 2-cc open-ended hypodermic syringe is used to measure out and transfer 0.4 cc of flux in each case.

Transfer the dishes to a Fischer burner and fuse at the lowest temperature possible. Keep the mixtures molten for 30 seconds and then remove and allow them to cool for 15 minutes before measuring the fluorescence.

The essential factor in the fusion step is uniformity of treatment of standards and the unknown insofar as possible. Minimum temperature and a short molten time are important to limit the dissolution of platinum in the flux which acts as a quenching element.

d. Uranium Standards and Blanks. One liter of a standard solution of uranium is prepared by accurately weighing about five grams of pure uranium metal and dissolving in a mixture of hydrochloric and nitric acids. A working standard in 2M nitric acid is made by diluting this solution exactly by a factor of one thousand. Aliquots of this solution are then used to obtain known amounts of uranium for the preparation of standard samples.

To correct for possible inclusion of uranium from the papers, reagents, vessels, and to some extent accidental contaminations a blank must be run. A clean filter paper is dissolved using the same reagents in the same amounts as those employed in dissolving the sample. Aliquots of this solution are carried through all the steps of the uranium determination and the level of their fluorescence is measured on the fluorometer.

Accurately known amounts of uranium, about 2 μg, are added to aliquots of the above blank solution. These standards are carried through

[15] J. A. S. Adams and W. J. Maeck, Anal. Chem. 26, 1635 (1954).

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all steps of the procedure to eliminate possible errors due to incomplete extraction of uranium, change in volume of the ethyl acetate, and related problems.

e. Measurement of the Fluorescence. The instrument used is a Jaco Galvanek-Morrison Fluorometer,[16] construction details of which can be obtained from the Jarrel-Ash Company.[17]

Filtered 3600 Å light is focused on the uranium sample and the resulting visible fluorescent light is filtered thru Corning 3484 and 9780 filters to isolate the 5500 Å uranium fluorescence. A 931A photomultiplier with peak response at 5500 Å is used to measure the light intensity. The measuring circuit is essentially a vacuum tube voltmeter. Shunt switches are provided to vary the sensitivity range. A warm-up time of at least 15 minutes, preferable an hour, is required for stable operation.

The intensity of the emitted fluorescent light is known to be a linear function of the uranium present (from 0.001 to 10 μg of uranium) and the response of the instrument is also known to be linear at a constant level of illumination.

The intensity of fluorescence of the blanks, the standards, and the filter paper samples are measured and the amount of uranium found in a given sample is calculated in the following way. If F_S is the reading for a standard known to contain S μg of uranium; F_X is that of a filter paper sample and F_B that of the blank, then the μg of uranium in a sample is:

$$\mu g \text{ U in sample} = S \cdot \frac{F_X - F_B}{F_S - F_B}$$

The duplicate measurements should agree to at least 10%; if not, additional determinations must be made since accidental contamination or loss is indicated.

If one knows the fraction of the original filter paper solution actually transferred to a dish, the bomb fraction (BF) present in the solution of the dissolved filter paper may now be calculated. The following formula includes all of the measured quantities.

$$BF = \frac{V_1}{A_1} \cdot \frac{V_2}{A_2} \cdot \frac{U_S}{V_S} \cdot \frac{A_W}{1000} \cdot \frac{A_3}{V_3} \cdot \frac{(F_X - F_B)}{(F_S - F_B)} \cdot \frac{1}{U_T}$$

[16] P. Galvanek, Jr. and T. J. Morrison, Jr., US AEC, ACCO-47 (1954).

[17] Jarrell-Ash Co., 26 Farwell St., Newtonville, Mass.

where V_1 = total volume of filter paper solution; A_1 = aliquot of filter paper solution; V_2 = total volume of ethyl acetate for sample; A_2 = aliquot of ethyl acetate for sample; U_S = weight of uranium in standard solution; V_S = volume of standard solution; A_W = aliquot taken of working standard; 1000 = dilution of standard to working standard; A_3 = aliquot of ethyl acetate for standard; V_3 = total volume of ethyl acetate for standard; F_X = fluorometer reading of sample; F_B = fluorometer reading of blank; F_S = fluorometer reading of standard; U_T = total uranium on barge.

f. Reagents. Mix 450 g Na_2CO_3, 450 g K_2CO_3, and 100 g NaF reagent grade for approximately six hours in a ball mill. Before mixing any batch of them fuse them in this ratio to be sure they are low in uranium content and do not provide a blank of interfering intensity. This mixture is somewhat hygroscopic and must be stored in a tightly closed container or preferably a desiccator.

Prepare a saturated aqueous solution of $Al(NO_3)_3 \cdot 9\ H_2O$ known by fluorescent test to be suitably free of uranium. If necessary extract uranium from this solution by the use of ethyl acetate.

6. Measurement of Number of Fissions in Sample

a. Discussion of Method. The amount of fission-produced energy in a nuclear explosion is directly related to the amount of fission-product activity formed. It is not practical to attempt to do a complete radiochemical analysis of all fission products in the debris, since most species decay with inconvenient rapidity; it is, however, possible to analyse for selected fission products of known fission yield.

The most convenient and direct measure of fission is obtained from the analysis of the active debris for the species Mo^{99}. This nuclide is produced in the thermal-neutron induced fission of U^{235} and Pu^{239} with a fission yield (i.e. atoms Mo^{99} formed per fission event) of 0.06, or 6%. (See for example, J. O. Blomeke, Oak Ridge National Laboratory Report No. ORNL-1783, Nov. 2, 1955). The decay scheme of Mo^{99} is shown in Figure 14.

If the radiations of Mo^{99} are detected with a gas-flow proportional counter or a Geiger-Muller Counter, only the β^- particles from the decay of Mo^{99} are counted with good efficiency. Corrections for the presence of genetically related Tc^{99} beta radiations as well as all gamma radiations may be neglected. Conversion electrons from Tc^{99m} are absorbed more than 99 percent by the air gap and counter window.

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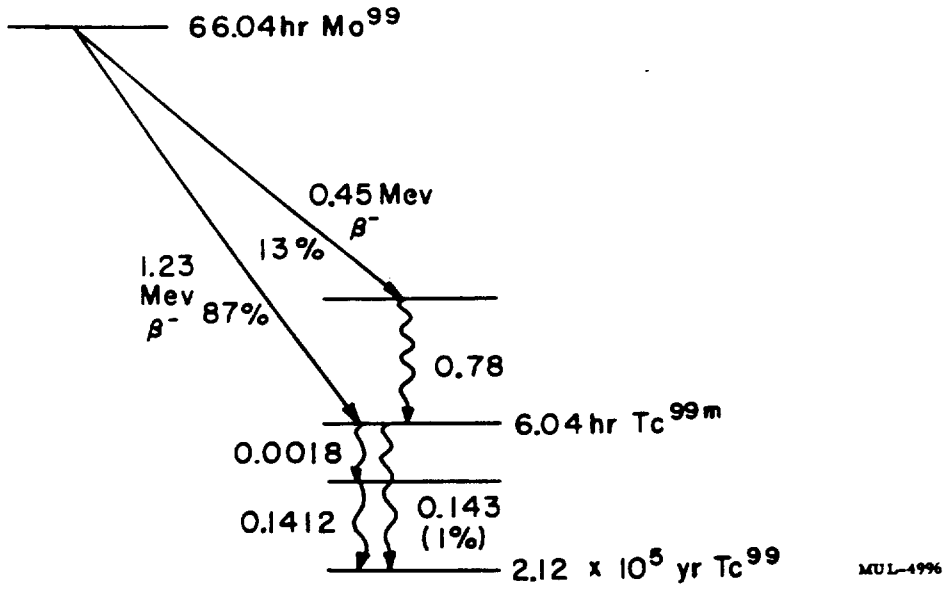
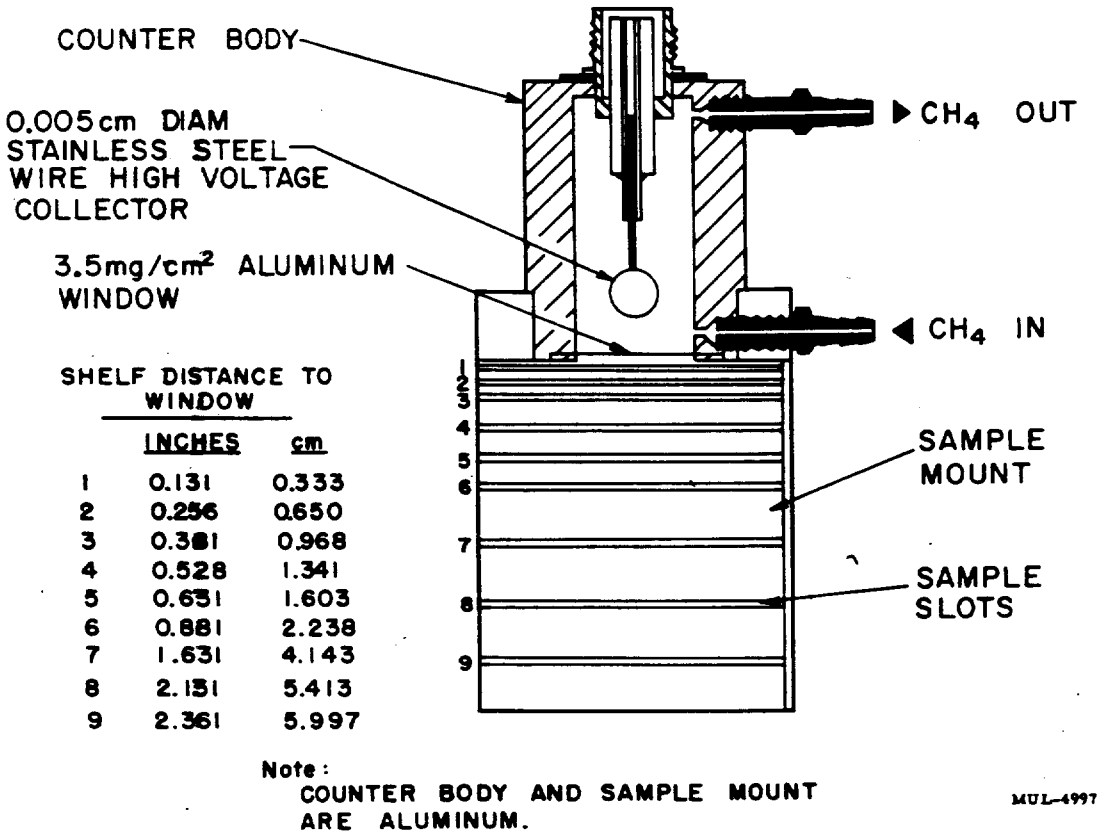


Fig. 14. Decay scheme of Mo^{99}.



SHELF DISTANCE TO WINDOW

	INCHES	cm
1	0.131	0.333
2	0.256	0.650
3	0.381	0.968
4	0.528	1.341
5	0.631	1.603
6	0.881	2.238
7	1.631	4.143
8	2.131	5.413
9	2.361	5.997

Fig. 15. Beta proportional counter and sample mount.

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Table II. Fission Yield of Mo^{99} from U^{235} as a Function of Bombarding Neutron Energy

Energy (Mev)	0	0.95	4.85	14.2
Percent fission yield	6.14[a]	6.10[a]	5.45[a]	5.17[b]

[a] J. Terrell, W. E. Scott, J. S. Gilmore, and C. O. Minkkinen, Phys. Rev. 92, 1091A (1953).

[b] J. Terrell, W. E. Scott, J. S. Gilmore, and C. O. Minkkinen, Item 55-136 (Presented at the American Physical Society Meeting, Sept. 3, 1953, Albuquerque, New Mexico).

The beta proportional counters (Figure 15) used to determine Mo^{99} disintegration rates are calibrated using Pb^{210} - Bi^{210} - Po^{210} samples of known disintegration rates obtained from the National Bureau of Standards. Pertinent data for each standard are provided by the National Bureau of Standards. These Ra D+E samples are counted in the same position relative to the counter as the Mo^{99} is to be counted. A thin (7mg/cm^2) aluminum absorber is placed close to the counter to absorb any α radiations from Po^{210} and β radiations from Pb^{210}. The observed counting rate is corrected for absorption by air gap, absorber, and 3.4 mg/cm^2 aluminum counter window, back-scattering from the Pd-Ag mount, and self-absorption of the PbO_2 electro deposit (see Appendix III for sample calculation). The corrected counting rate is divided by the known absolute disintegration rate of the standard sample to give the efficiency, i.e., the solid angle of the counter for a weightless sample mounted on a weightless mounting.

Previously, a carrier-free sample of Mo^{99} was prepared and a measured portion evaporated carefully on a thin Mylar (organic polymer) film supported on a frame. Another measured portion of the active solution was added to a known amount of inactive molybdenum in solution as Mo(VI). The solution was well mixed and heated to 90°C for 15 minutes. Then $PbMoO_4$ was precipitated, washed twice with water, once with acetone, and dried for one hour at 130°C. After cooling to room temperature, samples of varying weight were prepared on thin aluminum dishes. All samples were mounted on thick aluminum holders and counted in the proper geometry. Figure 16 shows the results of these measurements.

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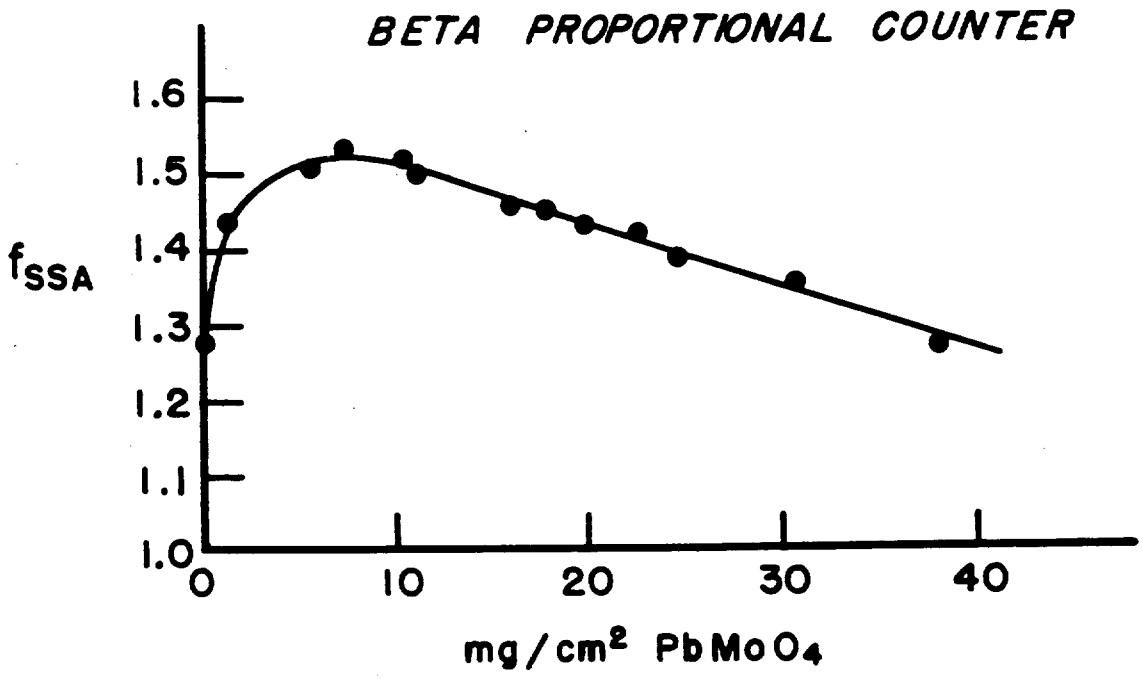

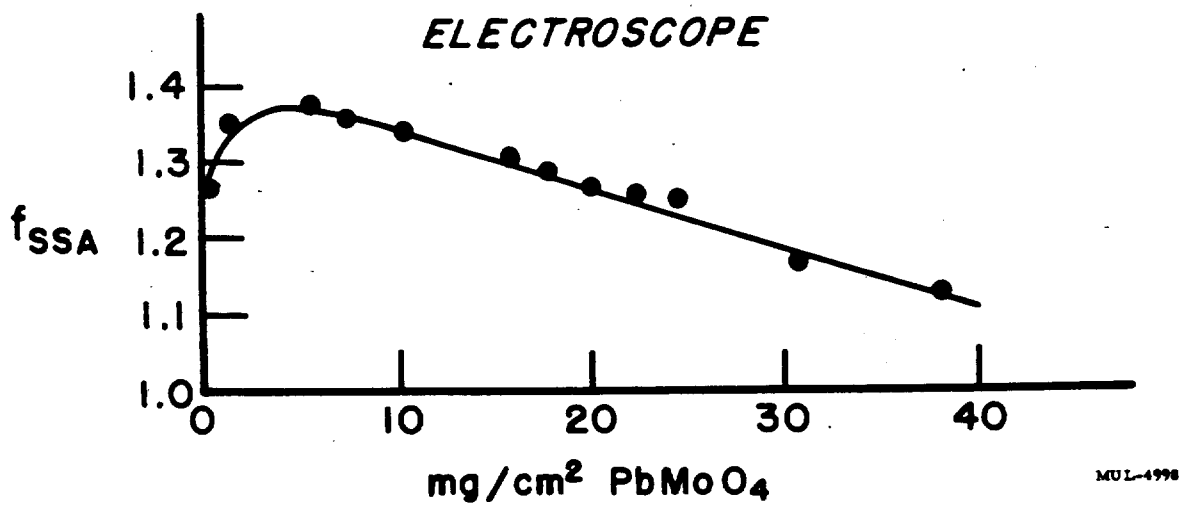

Fig. 16. Sample correction factors for Mo^{99} as $PbMoO_4$ mounted on very thick aluminum backing.

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One may now correct the observed Mo^{99} counting rate for the effects of self-scattering, back-scattering, self-absorption, and absorption due to air gap and counter window in the same manner as for the Ra D+E standard. The aliquot mounted on Mylar is taken as a good approximation to a weightless sample on a weightless backing.

Given the absolute disintegration rate of a sample of Mo^{99} separated from the bomb debris, the following sequence of calculations is performed;

1. The disintegration rate is extrapolated back to the time of detonation, using the known half-life of 66.04 hours.

2. The number of disintegrations per unit time at the time of detonation, is converted into atoms of Mo^{99} through the relationship

$$\text{atoms of } Mo^{99} = \frac{\text{disintegration rate x half-life}}{\ln 2}$$

3. The number of fission events giving rise to the derived number of molybdenum atoms is derived through the relationship

$$\text{numbers of fissions} = \frac{\text{atoms of } Mo^{99}}{\text{fission yield of } Mo^{99}}$$

The short half-life of Mo^{99} may render impossible the direct confirmation of the above series of measurements. However, it has been our experience that the 282 day Ce^{144} is also an excellent fission indicator and will give results similar to those from Mo^{99}. The determination of Ce^{144} must wait for at least two weeks after the detonation to allow the Ce^{143} to decay sufficiently for accurate determination, hence our choice of Mo^{99} for this demonstration.

b. Chemical Separation Procedure. Radiochemical analysis for Mo^{99} is routinely performed using carrier, i.e., a known amount of inert molybdenum added to the active material. Once isotopic exchange has been attained, chemical separations performed on milligram amounts of added carrier molybdenum will serve to separate the radio-molybdenum in exact proportion. When the carrier material is completely purified from extraneous activities, it is precipitated in weighable form and weighed to determine the fraction recovered.

Tracer and carrier molybdenum ions exchange readily in hydrochloric acid medium if nitrate is present to insure the complete conversion of all

molybdenum to Mo(VI).

A measured aliquot of the sample solution is added to a measured aliquot of previously analyzed ammonium molybdate solution. After thorough mixing, the solution is brought to pH 5 with ammonium acetate-acetic acid buffer, and 0.1 M $Pb(NO_3)2$ solution is added to precipitate the molybdenum lead molybdate. The sample is centrifuged and the supernatant is discarded. The precipitate is dissolved in 9 M HCl and the solution is poured through a column packed with anion exchange resin (Dow Chemical Company Resin "Dowex A-1"), previously treated with 9 M HCl. When all the active solution has passed through, the molybdenum is located in an adsorbed band at the top of the resin column. The following solutions are then passed in turn through the column to remove impurities: 10 milliliters (ml.) of 9 M HCl; 10 ml. of 0.1 M HCl; 1 ml. H_2O; 5 ml. of 3 M NH_4OH; 1 ml. H_2O. The molybdenum is then removed from the resin by passing through 15 ml. of 4 M HNO_3. A few drops each of sodium tungstate solution and silver nitrate solution are added to the eluate and the solutions mixed; then sufficient dilute hydrochloric acid is added to precipitate the added silver as silver chloride. The solution is digested in a hot-water bath to coagulate the mixed precipitates of tungstic acid and silver chloride and the precipitates are centrifuged off and discarded. The tungsten and silver precipitations are repeated. A small quantity of a solution containing Fe^{+3}, La^{+3}, Te^{+4} and Zr^{+4} is then added to the supernatant and precipitated with NH_4OH at pH 10 or higher for further decontamination. The precipitate is rejected. More Fe^{+3} and La^{+3} are added to the supernatant (which is ammoniacal) and the resulting precipitate rejected. The supernatant solution is then acidified with acetic acid to pH 5 and 0.1 M $Pb(NO_3)_2$ solution is added to precipitate the molybdenum as lead molybdate. The precipitate is washed with water and acetone and dried.

The dry precipitate is transferred to a weighed aluminum dish, the dish and contents are re-weighed, and the precipitate fixed in place by a few drops of diluted lacquer. The weight of recovered lead molybdate is determined by difference. The small dish is fastened with adhesive tape to a support suitable for insertion into the counting equipment and is counted once or twice daily for several days. The lacquer must be thoroughly dry before the counting is started, since the lacquer solvent exerts a pronounced effect on the counting rate.

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This separation procedure for molybdenum has been described by Gunn, Hicks, Stevenson and Levy, Physical Review, 107, 1642 (1957). Analyses are run in triplicate or quadruplicate to minimize experimental errors.

c. Treatment of Data. Each individual counting rate measurement is subject to two corrections. After recording an event, a counting instrument is insensitive for a period known as the "dead time", which we may represent by the symbol τ. Then if there are R events per unit time, the instrument is insensitive for a time $R\tau$ and operative for a time $1-R\tau$ in each unit time. The true counting rate then is $R \times 1/(1-R\tau)$. In the instruments used the dead time τ is so small (5 to 6 μ sec) that at ordinary counting rates the correction may be neglected. There is also a correction (due to the "background" rate of the counter) that is the counting rate in the absence of the sample. Background may be due to cosmic radiation, radioactive contamination of the counter, or electronic noise in the amplifier circuits; it is considered to vary only slowly with time. A measurement of the background rate made shortly before or after the measurement of the sample counting rate will yield a number which is subtracted from the measured rate to give the true counting rate of the sample.

The observed corrected counting rate for a pure sample of Mo^{99} will decrease exponentially with a half-life of 66.04 hours. The activity of the Tc^{99} and Tc^{99m} daughters activities are 99 percent adsorbed by the air gap and counter window and thus can be neglected. The counting rate for each sample can be extrapolated back to the time of the detonation to give an "initial rate" R_o.

The calculations are then as follows:

Let

$$y = \frac{\text{weight } PbMoO_4 \text{ recovered}}{\text{weight of Mo as } PbMoO_4 \text{ added as carrier}}$$

$$a = \frac{\text{volume of aliquot taken for analysis}}{\text{volume of total sample}}$$

$$f_{SSA} = \text{proper ordinate of Figure 16}$$

$$t = \text{mg/cm}^2 \text{ air gap + counter window}$$

$$\mu = \frac{0.693}{42} \frac{cm^2}{mg}$$ absorption coefficient for β radiation of Mo^{99}

g = fraction of disintegrations detected by counter as measured with Ra D+E standard

$$\text{disintegration rate of } Mo^{99} = \frac{R_o e^{\mu t}}{y \cdot a \cdot f_{SSA} \cdot g} = N\lambda$$

where N = Mo^{99} atoms

$$\text{and } \lambda = \frac{\ln 2}{66.04 \cdot 60} = 1.749 \times 10^{-4} \text{ min}^{-1}$$

$$\text{fissions represented by sample, f} = \frac{N\lambda}{1.749 \times 10^{-4} \times \text{fission yield of } Mo^{99}}$$

d. Calculation of Fission Yield. Given the above information on number of fissions and amount of uranium in the sample the fission yield can be calculated as follows:

$$\text{Fission yield in megatons} = \frac{\text{initial uranium x fissions in sample}}{\text{uranium in sample x } 1.45 \times 10^{26} \text{ fissions/megaton}}$$

e. Fission Ratio Determination. With the results of the fireball measurement of total yield and the radiochemical measurement of fission yield, the fission fraction can be calculated as shown:

$$\text{Fission ratio} = \frac{\text{Fission yield in megatons}}{\text{Total yield in megatons}}$$

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APPENDIX III. GEOMETRY CALCULATION

Let

$$f_B = \frac{\text{counting rate on Pd - Ag backing}}{\text{counting rate on weightless backing}} = 1.66^{\text{ref. 18}}$$

$$f_{SA} = \frac{\text{counting rate of } PbO_2 \text{ sample}}{\text{counting rate of weightless sample}} = 1.09$$

$\mu = \frac{\ln 2}{35} \frac{cm^2}{mg}$ absorption coefficient of β radiation of Ra E

t = mg/cm^2 air gap + counter window + absorber

A = measured counting rate

D = disintegration rate of sample

$$\text{geometry, } g = \frac{A \cdot e^{\mu t}}{f_B \cdot f_{SA} \cdot D} .$$

APPENDIX IV. FISSION CALCULATION FROM ELECTROSCOPE DATA

A. Calibration of Electroscope

The activity of the Ra D+E standard is measured on the electroscope in units of divisions per minute, Z.

$$\text{geometry, } G - \frac{Z \cdot e^{\mu t}}{f_B \cdot f_{SA} \cdot D} = \frac{\text{div}}{\text{min}} \Big/ \frac{\text{disintegrations}}{\text{min}}$$

Where symbols are the same as for the beta proportional counter and the factors have the same values. The response of the electroscope to Mo^{99} is approximately the same as for Ra (D+E), since the beta energies are approximately the same.

B. Calculation of Fissions

This calculation is the same as for the beta proportional counter where R_o is in divisions per minute and g is replaced by G.

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[18] B. P. Burtt, Nucleonics 5, No. 2, 28 (1949).

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